LABORATORY AND FIELD-BASED ASSESSMENTS TO DETERMINE THE ANTHROPOMETRIC AND PHYSIOLOGICAL CHARACTERISTICS OF ELITE SOCCER PLAYERS

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ABSTRACT

This thesis investigated the anthropometric, aerobic and anaerobic characteristics of elite male and female soccer players. Forty-three male (age, 23.6 ± 5.5 years; stature, 1.86 ± 0.13 m; body mass, 89.5 ± 16.5 kg) and eighteen female soccer players (age, 29.7 ± 9.5 years; stature, 1.69 ± 0.68 m; body mass, 64.6 ± 9.7 kg) from the highest respective English domestic leagues participated in the studies. The male soccer players were assessed on three occasions; End of Season (EOS), Prior to Pre-season (PTP) and Post Pre-season (PPS), performing a motorised treadmill incremental test to determine $\dot{V}O_{2max}$ and sum of eight skinfolds to estimate body fat. Female soccer players were assessed on a single occasion at the start of pre-season, performing repeat sprint ability (RSA) assessment (7 x 30m in 20 sec intervals) and sum of eight skinfolds; as well as friendly matches monitored for physical loading using global positioning satellite system (GPS) devices. The elite male players' estimated body fat was lowest EOS, however $\dot{V}O_{2max}$ values were also lower (55.5 ± 4.8 $ml \bullet kg^{-1} \bullet min^{-1}$) than PTP (56.7 ± 6.5 $ml \bullet kg^{-1} \bullet min^{-1}$) and significantly lower than EOP (61.7± 6.1 $ml \bullet kg^{-1} \bullet min^{-1}$) ($r = 0.70$, $R^2 = 0.32$; $p < 0.01$). Females' estimated body fat correlated significantly with RSA performance ($r = 0.71$, $R^2 = 0.32$; $p < 0.01$). RSA was also significantly correlated to the number of match-based high intensity efforts performed (speeds ≥ 4.1 $m \bullet s^{-1}$) ($r = -0.77$, $R^2 = 0.52$; $p < 0.01$). This study demonstrates that in elite male soccer players, $\dot{V}O_{2max}$ values observed after pre-season are significantly greater than the preceding post-season results, illustrating a decline in aerobic capacity toward the end of a competitive season. Additionally, body fat and anaerobic capability (RSA) appear to be interrelated within elite female soccer, as well as the RSA results being associated with players' capability to perform repeated high intensity efforts during match-play.

DECLARATION

I declare that this thesis is my own unaided work. It is being submitted for the degree of Master of Science (Research) at the University of Bedfordshire.

It has not been submitted before for any degree or examination in any other University.

Name of candidate: Tessa E Morris signature:

Date: 11th February 2015

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LIST OF ABBREVIATONS

ANOVA	Analysis of Variance
BIA	Bioelectrical Impedance Analysis
bpm	Beats per Minute
cm	Centimeters
DEXA	Dual x-ray absorptiometry
EOP	End of Pre-Season
EOS	End of Season
EPL	English Premier League
GPS	Global Positioning System
h	Hours
ISAK	International Society for the Advancement of Kinanthropometry
kg	Kilograms
m	Meters
min	Minutes
ml	Millilitres
MRI	Magnetic Resonance Imaging
MSFT	Multi-stage fitness test
O_2	Oxygen
PTP	Prior to Pre-Season
RE	Running Economy
RER	Respiratory Exchange Ratio
RPE	Rating of Perceived Exertion
RSA	Repeat Sprint Ability
secs	Seconds
SF	Skinfold Measure
The FA WSL / WSL	The FA Women's Super League
UEFA	Union of European Football Associations
$\dot{V}CO_2$	Volume ($\dot{V}$), Carbon dioxide (CO_2)
$\dot{V}O_{2max}$	Volume ($\dot{V}$), Oxygen (O_2), Maximum ($_{max}$)
$\dot{V}O_{2peak}$	Volume ($\dot{V}$), Oxygen (O_2), Peak ($_{peak}$)
yrs	Years

CHAPTER I GENERAL INTRODUCTION

The popularity of male professional soccer (football) is well known, with the Premier League being the most watched league in the world (www.premierleague.com). Women's soccer has also seen considerable evolution over the last two decades (Datson et al, 2014) with the FA Women's Super League (The FA WSL or WSL) having peak viewing figures in 2011 on par with the men's Scottish Premier League (www.fawsl.com). In comparison with other sports and activities, soccer is very well represented from a sports science perspective, with a World Congress of Science and Football every four years since 1987, academic programmes formalised from 1991 and the majority of clubs now employing specific Sports Science expertise (Reilly and Williams, 2003).

Despite these vast advances within the field, particularly since the 1980's, there are still essential challenges to overcome; for instance, the ability to measure the demands imposed during training and match days with the same methodology (global positioning system (GPS) devices are now widely used as the measurement equipment during training, and semi-automated multi-camera image recognition systems, such as ProZone® (described within section 3.1.3), leveraged within games). Additionally for women's soccer, the lack of access to these technologies for the measurement and monitoring of training and match demands presents disparity and barriers toward physical preparation progression; for example, more precisely measuring individual player loading and estimated match-day work rates completed. This study therefore aims to investigate two areas of research within male and female elite soccer which highlight, that despite significant interest toward soccer science and a wealth of applied science practitioners, there are still key areas of importance that require attention.

The first area of focused research for this thesis is within professional male soccer (Chapter II), where the fluctuations of aerobic and anthropometric attributes, and their interrelationship, have not been adequately identified within top-flight English domestic players over the off-season and pre-season. This is problematic given the Premier League calendar is largely split into just three significant periods; the off-season, lasting four to six weeks, pre-season, four to five weeks and the English Premier League (EPL) competitive schedule lasting up to forty two weeks. The off-season therefore provides a rare opportunity for prolonged recovery and residual fatigue to dissipate (whilst maintaining key physiological attributes) and pre-season offers the only period for progressive overload and adaptation to occur (due to the recurring 'fixture, recovery and preparation cycle' that is necessary to adopt with the EPL fixture schedule). Consequently, key underpinning physiological attributes, such as optimising players' body fat and aerobic capacity for increased efficiency of movement and recovery capabilities for instance, must be enhanced sufficiently ahead of the long and highly competitive maintenance phase. This research will therefore make a novel and valuable contribution to the elite soccer literature by identifying the anthropometric and physiological adaptations of professional players at EOS, PTP and EOP, as well as providing data to support evidence based practical application of strategies to best optimise players' anthropometry and physiology over these time-periods.

The second topic of research within this thesis is to investigate key performance parameters within elite female soccer (Chapter III), which have been well represented within the male literature, but are significantly lacking in the female domain. It's important to note that gender differences exist in soccer (Andersson et al, 2010; Krustrup et al, 2003; Vincent and Glamser, 2006), so transition of knowledge should be approached cautiously or in some instances avoided. This study therefore aims to build on the current scarcity of research, notably within, but also between; anthropometry (sum of eight skinfolds), RSA (maintenance of speed whilst delaying fatigue) and match-based capabilities (specifically, repeated high intensity efforts). These are areas that are noteworthy within the elite male soccer literature; for instance the numerous anthropometry studies conducted (table 2.0), body fat percentage upper-limits suggested (Gil et al, 2007) and even investigation into the association of body composition with league position (Arnason et al, 2004). However, female anthropometry data is missing this rigor, with just seven publications in the last decade (Datson et al, 2014) and limited association to performance measures (Can et al, 2004; Sedano et al, 2009; Polman et al, 2004). This research aims to add to the body of literature, providing anthropometric characteristics for top-flight WSL soccer players, but additionally investigating the association between sum of eight skinfolds and RSA. A relationship previously observed within professional male players and individual sprint performance (Ostojic, 2003) as well as the fundamental principle that sprint performance is determined by a high ratio between body mass and power (Chelly and Denis, 2001; Cronin and Sleivert, 2005; Wayand et al, 2000). Mohr et al (2003) define soccer at the highest standard being characterised by the ability to perform high intensity work repeatedly. Despite this, anaerobic capabilities are largely unknown within the female game, with the closest publication to investigate RSA within elite players assessing just three sprint repetitions (Krustrup et al, 2010) and a single study existing that calculated match sprint occurrences and recovery periods (Vescovi, 2012). Therefore, as well as establishing elite female RSA values using a fixed protocol assessment, this second thesis study additionally aims to distinguish its aptitude to identify repeated high intensity effort abilities during match-play.

CHAPTER II THE ANTHROPOMETRIC AND PHYSIOLOGICAL IMPACT OF THE OFF-SEASON AND PRE-SEASON WITHIN ELITE MALE SOCCER PLAYERS (STUDY A)

2.0 Introduction

The assessment of body composition and physical performance is now commonplace within professional soccer, albeit the methods leveraged can vary greatly between clubs (in terms of measurement equipment and protocols performed). There is a large emphasis placed on these assessments and the expectation that players will reach specified targets. This scrutiny has now been extended to the off-season, where previously it was accepted that players may return to pre-season in unsatisfactory physical condition, but now given the lengthy season (around forty-two weeks, pending competition involvement) and short pre-season (often six weeks) it is widely seen as a requirement for players' peak physical fitness and body composition to remain readily redeemable. Despite this prospect, the activity profiles and dietary habits of players during the off-season are often notionally guided and adherence unmonitored. Whilst this approach provides a complete break for the players, it also introduces the opportunity for large individual variation, with the conscientiousness professional returning as anticipated and select players being non-compliant. Although this is simply an anecdotal preamble, it's important to note that de-training or adaptations occurring during off-season and pre-season are rarely monitored, which may explain the lack of literature surrounding these important periods in the calendar.

This research will therefore make a valued contribution toward the application of soccer science during the off-season and pre-season by better understanding the modern professional soccer players' aerobic and anthropometric conditioning and de-conditioning over these periods. Additionally, this thesis will add to the academic literature by directly measuring seasonal variation (EOS, PTP and EOP) of aerobic capacity and body composition (sum of eight skinfolds, as per International Society for the Advancement of Kinanthropometry (ISAK) (Marfell-Jones et al, 2006), to determine body fat), never before published with Premier League footballers.

2.1 Review of Literature

The physical attributes of soccer players are an important factor toward successful performance, particularly at the elite level (Apor, 1988; Rampinini et al, 2009). The testing and profiling of individual players occurs on a regular basis, in order to optimise training strategies (Svensson and Drust, 2005) and minimise detrimental and often costly match day fatigue (Reilly, 1997; Mohr et al, 2003). Despite the significance of fitness, and the supposed difficulty increasing these levels throughout the season (due to the regularly of fixtures and focus therefore on recovery) (Owen et al, 2012; Reilly, 2006), there is very little emphasis within the literature toward effective off-season and pre-season strategies. This scenario is echoed in relation to corresponding body composition, where the elite male soccer literature base is prolific (Table 2.0), but offers few insights or solutions to off-season or pre-season adaptations. Closing this gap of knowledge during these periods would be advantageous, given the largest fluctuations of the EPL calendar occur then, and how crucial it is to prepare effectively for the season ahead. Although the physiological and anthropometric characteristics provide only a proportion of the multifactorial impacts of an effective physical conditioning programme for soccer, these are attributes found to have large seasonal fluctuations (Carling and Orhant, 2009; Clark et al, 2008), be markedly different between top players (Reilly et al, 2000; Stølen et al, 2005) and perceived to have a relationship with work-rate (Ekblom, 1986; Rienzi et al, 2000; Rampinini et al, 2009). Despite these factors and clear interrelationship, in terms of efficiency of movement and work-rate capabilities, only a handful of papers are dedicated to the association of body composition and physical performance within a soccer capacity (Clark et al, 2008; Reilly et al, 2000; Wong et al, 2009). Therefore, the following sections review the anthropometric (section 2.1.0) and physiological (section 2.1.1) literature in isolation, with a view to gaining a better understanding of these in relation to EPL soccer demands and players through the present research undertaken.

2.1.1 Anthropometric Measures

Current methods of estimating body composition in athletes have limitations, either due to expense and accessibility (magnetic resonance imaging (MRI), dual x-ray absorptiometry (DEXA)), involve exposure to radiation (DEXA) or are time consuming for applied practitioners and potentially lack accuracy (skin fold thicknesses and Bioelectrical Impedance Analysis (BIA), respectively). Comparison between methods has demonstrated significant inter-reliability and often intra-reliability variation (Sardinha et al, 1998; Stewart and Hannan, 2000), making it difficult to determine associations with other body composition method results cited in the literature.

This difficultly also exists within methods, such as skinfold measurements where a variation of locations for the skinfolds are used on a regular basis, as well as number of sites measured (Parízková., 1977; Casajús, 2001; Chamari et al., 2004; for example). Despite this, skinfolds are widely used in applied settings, in particular following the International standards for anthropometric assessment (Marfell-Jones et al, 2006), where the same practitioner should be taking repeat measures to reduce error (Hume and Marfell-Jones, 2008). This is important to note when applying this method in the field, in order to successfully differentiate between meaningful change and simply that of inter-practitioner error. Additional measures and prediction models can also be used in order to predict lean body mass (Lee et al, 2000; Slater et al, 2006).

In terms of elite soccer anthropometric data, this is plentiful within male populations, spanning a variety of age-groups, countries, performance levels and position specific data. However, these have also been collated using a range of methods (Milsom et al, 2015; Raven et al, 1976; Strudwick et al, 2002), so comparison should be approached with caution due to varying accuracy (Bentzur et al, 2008). Ensuring accuracy of measurement is important with body composition in general, due to being able to distinguish meaningful change over time, but particularly within elite sport when decisions are made around energy balance and training adaptations. In Professional soccer, it's possible that decisions are also made around eligibility to train or play and even financial repercussions, due to a player's body composition. A summary of elite male soccer anthropometrics can be found in Table 2.0, adapting and building on a review completed by Strauss et al (2012), excluding junior player data or levels below National or First Division soccer.

It has been suggested that the low body fat percentages associated with professional soccer are due to the high intensity and frequency of training (Kalapotharakos et al, 2006) and that the percentage fat of male soccer players should not exceed 11.5-12% (Gil et al, 2007). Arnason and colleagues (2004) demonstrated a trend between skinfold measures and team success; although this was not found to be significant (P = 0.07), however it may have highlighted a relationship that has been demonstrated between physical performance, technical performance, fatigue and league standings in soccer (Rampinini et al, 2009). Although, this theory is opposed by a recently published study within the English Premier League, which identifies lean mass (using DXA) as the distinguishing factor between age-groups of players and not body fat (Milsom et al, 2015).

Table 2.0 Anthropometric profile of elite male soccer players adapted and extended from Strauss et al (2012)

Study	Subjects	Method	Level / Country	Body Mass (kg)	Stature (cm)	Body Fat (%)
Al-Hazzaa et al (2001)	n = 23	SF (2)*	Saudi elite	73.1 ± 6.8	177.2 ± 5.9	12.3 ± 2.7
Arnason et al (2004)	n = 236	SF (6)*	Icelandic elite and First Division	77.0 ± 0.7	181.7 ± 0.5	9.9 ± 0.5
Casajús (2001)	n = 15	SF (6)*	Spanish First Division	78.5 ± 6.6	180.0 ± 0.1	8.6 ± 9.1
Boone et al (2012)	n = 289	SF (10)*	Belgium First Division	77.4 ± 7.1	182.4 ± 1.8	11.0 ± 2.5

Kalapotharakos et al (2006)	n = 19	SF (3)*	National Greek league	78.0 ± 4.5	180.0 ± 0.5	9.0 ± 1.8
Kalapotharakos et al (2011)	n = 12	SF (3)*	National Greek league	75.7 ± 5.3	179.0 ± 0.6	9.2 ± 1.9
Strudwick et al (2002)	n = 19	SF (4)*	Premier League	77.9 ± 8.9	177.0 ± 0.6	11.2 ± 1.8

* SF signifies Skin Fold Measure, including number of site locations

When considering the current literature within elite male soccer, ethnicity appears to often be overlooked, despite significant body fat differences exhibited (Sutton et al, 2009). This raises an important issue given the EPL has on average fourteen players of foreign nationality per squad (Pedace, 2008) and further research in this field may have a positive impact on promoting individualisation of body composition targets by practitioners and expectations from coaches.

The majority of studies have also been conducted on a single occasion (Al-Hazzaa et al, 2001; Arnason et al, 2004; Boone et al, 2012; Chamari et al, 2004; Kalapotharakos et al, 2006), which provide useful baseline characteristics, however more advanced intervention or observation of adaptation over time would benefit research progression within this domain. For instance, just a couple of examples exist (albeit not conducted within the EPL) where anthropometric change has been tracked over two and three time periods (Casajús et al, 2001 and Kalapotharakos et al, 2011, respectively). A greater number of Premier League focused publications would be advantageous, in terms of providing data specific to the off-season, pre-season as well as the competitive period. This is particularly pertinent given league set-ups in countries other than England may have a longer off-season and pre-season than the EPL, as well as potentially a mid-season break, and therefore seasonal anthropometric data is unlikely to be transferable. Additionally just a single study, conducted in the English Championship, has established inter-seasonal variation over multiple time-periods (Clark et al, 2008). A greater level of research over multiple seasons would extend our scientific understanding of how the demands of the EPL are reflected on players' physiology, perhaps more crucially providing applied practitioners with underpinning science from which to base interventions.

2.1.2 Physiological Measures

Measurement of the physical capacity of top-class players provides a good base from which physiological requirements can be determined, due to adaptation reflecting demand (Reilly et al, 2000). Although soccer is dominantly an endurance game, where players in the English Premier League cover around 10,700 m total distance (Bradley et al, 2009), the anaerobic component is of key importance for execution of a successful performance (Aziz et al, 2000). Despite some researchers concluding that laboratory based assessments, including $\dot{V}O_{2max}$, are not sensitive measurements of intermittent field based endurance capacity (Bangsbo and Lindquist, 1992; Clark et al, 2008) and are functionally imprecise (Wisløff et al, 1998), these have been found to successfully differentiate between adult and young professional players (Angius et al, 2012), level of performance (Apor, 1988) as well as total distance covered, work intensity performed, number of sprints completed and involvements with the ball during matches (Helgerud et al, 2001).

Information available of the cardio-respiratory endurance of soccer players is substantial, with the earliest research occurring in 1970 (Carù et al, 1970), since which physiological specifics for elite male soccer players are available from Africa (Chamari et al, 2004) Asia (Adhikari and Kumar Das, 1993; Al-Hazza et al, 2001; Aziz et al, 2005; Chin et al, 1992), North America (Rhodes et al, 1986), South America (Cossio-Bolanos et al, 2015) and Australia (Green, 1992), with the majority originating from Europe (see Table 2.1). Comparatively few papers exist from the English top divisions (Clark et al, 2008) and findings originating overseas shouldn't be viewed as a direct transfer to the EPL, given the potential for differing demands imposed (Drust et al, 1998; Rienzi et al, 2000), league structure (such as a winter break stipulated and when pre-season occurs, for example) and the number of competitive fixtures, including National and International cup competitions. The impact of these variables on $\dot{V}O_{2max}$ is yet to be established, in addition to domestic fluctuations, such as frequency of league matches, short or prolonged periods without match-play or training (injury occurrence for example) and change in relation to club personnel and training methods (Clark et al, 2008). This presents a fundamental question in terms of how and when soccer specific physical attributes, such as aerobic capacity, are measured in order to distinguish when de-training is or may occur. Further research into the direct impact of training demand fluctuations or additional fixtures would be incredibly valuable in terms intelligently applying interventions to sustain or even increase players' conditioning during the season.

Alternative submaximal measures have been advocated as more likely to detect meaningful change to aerobic fitness throughout a soccer season (Svensson and Drust, 2005), which has been substantiated by subsequent studies (Clark et al, 2008; Owen et al, 2012). Running economy (RE) for instance has been demonstrated on numerous occasions to significantly develop with small-sided game interventions (Chamari et al, 2005; Dellal et al, 2011, Impellizzeri et al, 2006) and although indirect benefits clearly exist (Hill-Haas et al, 2009; Owen et al, 2012), RE has yet to find a direct relationship with physical match performance indices. This is unsurprising given the lack of soccer specificity involved, and that Premier League footballers have been found to change direction 726 ± 203 times during a match and only 20.6% of game time purposely moving forwards (Bloomfield et al, 2007). Measurements of blood lactate may provide a useful additional indicator of workload (Coutts et al, 2009) and be sensitive to training alterations (Edwards et al, 2003; Helgerud et al, 2001), but similarly, perhaps not advisable to be used as a predictor of physical match performance (Svensson and Drust, 2005). This is particularly given blood lactate measurements are significantly altered by the last efforts of match-play (Datson et al, 2014) and regular measurement opportunities are clearly not feasible.

Table 2.1 Cardiorespiratory $\dot{V}O_{2max}$ results from European elite senior male soccer players

*Player position inclusion information not available **All player positions included

Study	Subjects	Test Instrument	Level / Country	$\dot{V}O_{2max}$ ($ml.kg^{-1}.min^{-1}$)
Apor et al (1988)	n = 8	n/a	Hungary National	73.9 ± 10.8
Arnason et al (2004)	n = 225**	VacuMed (17620 and 17630; Ventura, CA)	Iceland (two highest divisions)	62.5 ± 4.8
Bangsbo (1994)	n = 65	n/a	Denmark Elite	58.22
Bunc (1992)	n = 15	n/a	Czechoslovak Elite	61.9 ± 4.1
Casajús (2001)	n = 15*	Medical Graphics-Cardiopulmonary Exercise System CPX	Spanish First Division (La Liga)	65.5
Clark et al (2008)	n = 42*	n/a	English Championship	61.6 ± 0.6
Faina et al (1988)	n = 27	n/a	Italian Professional	58.9 ± 6.1
Kalapotharakos et al (2011)	n = 12*	TrueMax 2400, ParvoMedics, Salt Lake City, UT, USA	National Greek league	58.1 ± 3.1
Matkovic et al (1993)	n = 44	n/a	Croatia Division One	52.1 ± 10.7
Puga et al (1993)	n = 21**	n/a	Portuguese First Division	59.6 ± 7.7
Rahkila and Luthanen (1991)	n = 31	n/a	Finland Senior	56.0 ± 3.0
Wisløff et al (1998)	n = 29***	Ergo Oxyscreen; Jaeger EOS sprint, Germany	Norwegian Elite Soccer League	63.7

*** Excluding goalkeeper data n/a - information not available

In terms of research undertaken to date, there are excellent reviews which encompass the multi-facetted demands of soccer, including physiological summaries (Hoff, 2005; Stølen et al, 2005; Svenson and Drust, 2005). No direct measurements appear to be published from the EPL however, with a single indirect example Davis and colleagues (1992), who made a prediction of $\dot{V}O_{2max}$ from the multi-stage fitness test (MSFT) (Léger et al, 1982) and Clark et al (2008) who studied direct physiological responses throughout multiple English Championship seasons. In addition, the demands of soccer within the professional game appear to be ever evolving (Reilly and Thomas, 1976; O'Donoghue, 2002; Bradley et al, 2009) and therefore continued assessment of modern top-flight soccer players would be advantageous, in particular to observe which attributes attain greatest development. In other words, what are the physiological attributes a modern player in the EPL requires in order to physically perform at their peak, repeatedly? A more conclusive answer to this question, regardless of technical or tactical objectives and taking position specific requirements into consideration, may also help to more specifically develop younger players.

Despite the use of maximal aerobic capacity as a marker of fitness in soccer players being disregarded to some extent in contemporary literature, it is worthwhile noting however that no studies have directly measured the impact of pre-season, arguably the most crucial time for aerobic unpinning and development. Mercer et al (1997) assessed the impact of pre-season training using the multistage fitness test and Handziski et al (2007) observed blood lactate response to a specifically designed field-based soccer set-up, before and after pre-season training. A greater appreciation of individual player and squad aerobic variations could support a more strategic off-season training volume and precise objectives for pre-season (to then be maintained over the season). Further literature within this field, such as the first study of this thesis, would therefore progress science in soccer, in terms optimising preparation of players over these periods.

The use of running economy, anaerobic threshold and corresponding blood lactate markers have been represented more regularly in recent literature, although these studies have tended to be relatively short term and involved small cohorts (Angius et al, 2012; Denadai et al, 2005; Jensen and Larsson, 1992) or have been unclear about the workload implemented, making them difficult to replicate from a research perspective (Impellizzeri et al, 2006; Owen et al, 2012). A systematic assessment of the aforementioned physiological indicators throughout the season, and consecutive seasons, would prove valuable if these markers can effectively distinguish a player's fitness status and capabilities during match-play. Field testing is currently the most common method of assessment within professional soccer, as well as on-going monitoring of day to day workloads; however, this is hugely dependant on a number of factors, including a player's motivation and conditions within which the assessment is conducted. Furthermore, time motion analysis has progressed significantly within professional soccer games (Carling et al, 2008), as well as greater accuracy of distinguishing training demands (Cummins et al, 2013). A combined overview of these 'external training loads' with directly measured physiological 'internal training loads' would be progressive toward a holistic understanding of total player load.

2.1.3 Literature Summary

Fitness levels are difficult to modify during the EPL season, owing to the number and limited opportunities in-between fixtures for high intensity training (Owen et al, 2012; Reilly, 2006). Despite this, there's very little emphasis on optimisation of post-season and pre-season training strategies to maintain or develop aerobic capacity. Similarly, the anthropometric literature is vast, but largely measured on one occasion (Al-Hazzaa et al, 2001; Arnason et al, 2004; Boone et al, 2012; Chamari et al, 2004; Kalapotharakos et al, 2006), with few insights into seasonal fluctuations (Casajús et al, 2001 and Kalapotharakos et al, 2011) and no examples existing around the EPL post-season and pre-season impact. Although soccer is a multifaceted game, with numerous performance indicators, both aerobic capacity and body composition have been highlighted as key attributes to successful performance (Ekblom, 1986; Rienzi et al, 2000; Rampinini et al, 2009) and can demonstrate large fluctuations (Carling and Orhant, 2009; Clark et al, 2008).

Therefore, this research aims to specifically target these two phases outside of the competitive season, where aerobic capacity and anthropometric variations have never before been identified in relation to off-season and pre-season demands, and specifically within the EPL. This will have an impact on applied practice, as well as subsequent performance, by promoting greater intelligence to off-season strategies (for instance, minimising de-training or enhancing individual approaches) and secondly providing evidence toward maximising pre-season adaptation (where gains are subsequently expected to be maintained for the duration of the season).

2.2 Methods

The following section details all protocols, procedures and materials utilised during the completion of Study A - the anthropometric and physiological impact of the off-season and pre-season within elite male soccer players. All assessment protocols were undertaken over three time-periods; May, at the end of the competitive season (EOS); July, prior to pre-season (PTP) and August, at the end of pre-season (EOP).

2.2.1 Health and safety

Approval by the University of Bedfordshire ethics committee was given (Appendix I) for testing procedures and collection of data for Study A. Prior to the commencement of testing all participants completed a standardised warm-up protocol in order to reduce the risk of injury. The face mask and pneumatac/turbine used for the $\dot{V}O_{2max}$ assessment were cleaned with soapy water and soaked in water mixed with Milton sterilising tablets. The head cradle, oxygen lines, heart rate strap and sensor were cleaned using soapy water and dried before further use.

2.2.2 Standardisation and familiarisation procedures

All test protocols were conducted at the same time of day, to minimise the potential effects of circadian rhythms (Drust et al, 2005). The testing environment was standardised, to maximise test reproducibility and to permit valid comparisons over time and between individuals and groups. Participants without previous experience of each protocol were habituated with a minimum of two practice attempts, to dissipate any impact of learning effects (Barnes, 2007).

Participants were requested to attend the testing following a day of rest, euhydrated and in a carbohydrate loaded state. It was also stipulated that participants should refrain from eating at least 3 hours (h) beforehand, as well as drinking coffee or beverages containing caffeine for at least 8 h before the start of physical testing. These test procedure prerequisites were adhered to by the participants.

2.2.3 Participants

A total of forty three elite male outfield soccer players (age, 28 ± 10 years; stretch stature, 1.86 ± 0.14 m; body mass, 89.5 ± 16.5 kg) from a club in the English Premier League were assessed over three time periods May / End of Season (EOS), July / Prior to Pre-season (PTP) and August / Post Pre-season (PPS). Prior to the commencement of testing, all participants were fully briefed on each element of the protocols they were being asked to complete and reminded that they could withdraw at any point. It was explained that all information collected during the course of the research will be kept strictly confidential and all data anonymised, with only the medical staff at the professional club having access to the system of coding for participants. Informed consent was obtained with gate-keeper permission from the First Team Fitness Coach, within the Medical and Sports Science Department.

2.2.4 Anthropometric Measures

Body weight was determined using digital scales (Seca Scales; Hamburg, Germany) and recorded to the nearest 0.1 kg. Stature was taken as the maximum vertical distance from the floor to the vertex of the head. A second measurer was required to check the heels were not elevated whilst stretch force was applied by the anthropometrist, cupping the subjects head and providing firm traction alongside the mastoid processes. Body composition was assessed using skin fold callipers (Harpenden Skinfold Callipers; Cranlea, Birmingham, Great Britain) with measures over eight locations; triceps, subscapular, biceps, iliac crest, supraspinale, abdominal, front thigh and medial calf. All anthropometric assessments were performed according to the procedures stipulated by the International Society for the Advancements of Kinanthropometry (Appendix III) by a professionally trained anthropometrist.

2.2.5 Physiology Measures

Each participant performed a treadmill step test, where the workload increased progressively throughout five stages, over a twenty minute period. The first stage start speed was determined by previous assessments performed by the participant or judged appropriately based on a comfortable running speed (a 10 km running pace / a pace they felt they could sustain for ~ an hour or Rating of Perceived Exertion (RPE) (Borg, 1976; Appendix XII) of 5). A gradient of one per cent was maintained throughout the step test and each stage comprised of continuous running for three minutes and thirty seconds (secs), where the participant was asked to jump off with legs astride the treadmill belt. During the final thirty seconds of each four minute stage, a measure of RPE was taken from each player using Borg's Rating of Perceived Exertion scale, as well as a finger prick sample using a 1mm lancet, collected in a 20mm capillary tube, subsequently mixed in 1.5ml Eppendorf tube containing hemolysing solution. This was then analysed using a Biosen Lactate analyser (Biosen C-line analyser, EKF Industrie, Elektronik GmbH, Barleben, Germany) for blood lactate concentrations. Heart Rate and metabolic measures, including Oxygen (O_2) consumption were also captured during this time period.

The step test was followed by a five minute rest period, after which the participant completed a maximal test to exhaustion to determine $\dot{V}O_{2max}$ (Volume ($\dot{V}$), Oxygen (O_2), Maximum (max)).

The penultimate stage speed on the step test provided the start speed for the maximal element of the assessment, which alternated increasing with gradient every sixty seconds (see Table 2.2).

Table 2.2 A table representing the speed and gradient increases during the $\dot{V}O_{2max}$ assessment protocol

Time (mins)	Speed (km/hr)	Gradient (%)
1	12	1
2	12	2
3	13	2
4	13	3
5	14	3
6	14	4
7	15	4
8	15	5
9	16	5
10	16	6

Novice subjects were familiarised with the equipment and procedure ahead of testing, with particular attention to the process of lowering themselves onto and from the treadmill belt, standing their legs astride and using the emergency button to stop the treadmill belt.

The treadmill (Woodway; Wisconsin, USA) and gas analyser (Cortex Metalyzer gas analysis system) were calibrated ahead of each testing occasion, with a particular focus on pressure, gas and volume. Participants were instructed to continue until volitional fatigue. The following objective measures were also used to confirm maximal exhaustion;

- When a plateau in O_2 uptake and exercise intensity relationship was observed.
- A respiratory exchange ratio (RER) of ≥1.15; calculated by dividing the volume of carbon dioxide (VCO_2) output measure by volume of oxygen ($\dot{V}O_2$).
- Final heart rate of within 10 beats·min^{-1} of predicted age-related maximum (equation 220 minus the age of the participant; Equation 2.0 (Fox et al, 1971)).
- Self-reported RPE of ≥ 19 on the RPE scale.

2.3.3 Statistical Analyses

The full data set collated from all subjects (n = 43) over three time points (May, July, August) was analysed in total initially using a correlation matrix, discounting missing data sets and highlighting areas of significance (accepted at the level of $p<0.05$). A one-way analysis of variance (ANOVA) with repeated measures method of analysis was further employed to determine the specific significance of identified variables between the three time points (May and July, July and August, May and August).

All data was analysed using a statistical software package (Statistica 8, StatSoft Inc. Oklahoma 74104, USA).

2.3 Results

2.3.1 Anthropometric Measures

The anthropometric profiles of forty three players were collated in total, throughout three time periods during the season (Table 2.3). A total of twenty eight elite male outfield soccer players (age, 24 ± 6 yrs; stretch stature, 1.86 ± 0.13 m; body mass, 89.5 ± 16.5 kg) completed all three time periods (EOS, PTP and EOP).

Table 2.3 A table to represent subject anthropometric data (mean ± standard deviation)

	Subjects	Age (yrs)	Body Mass (kg)	Stature (cm)	Sum of 8 Skinfolds (mm)
May	n = 41	28.0 ± 10.0	89.5 ± 16.5	186 ± 13.5	79.8 ± 41.2
July	n = 35	28.1 ± 9.9	89.6 ± 17.6	186 ± 13.3	77.1 ± 35.9
August	n = 30	28.3 ± 9.9	90.7 ± 15.9	186 ± 13.3	66.1 ± 26.0

The sum of eight skinfolds measured of the twenty eight players that completed all three assessment occasions ranged from 59.3 ± 20.7 mm (EOS), 70.0 ± 28.8 mm (PTP), 66.1 ± 26.0 (EOP), represented by figure 2.0. A relationship was observed between these time periods, in terms of sum of eight skinfold measurements being lowest in May, EOS, highest in July, PPS, and a value in-between these two results was observed in August, EOP. However, no significant differences were highlighted between these time points in terms of the anthropometric measures obtained (P > 0.05; Appendix IV), which may be as a result of the individual player variation observed (figure 2.1; Appendix XVII). The effect size calculated between May and July was moderate (-0.43) and small between July and August and from May to August (0.14 and -0.29, respectively). Additional anthropometric values and correlations can be found within Appendix IV and V.

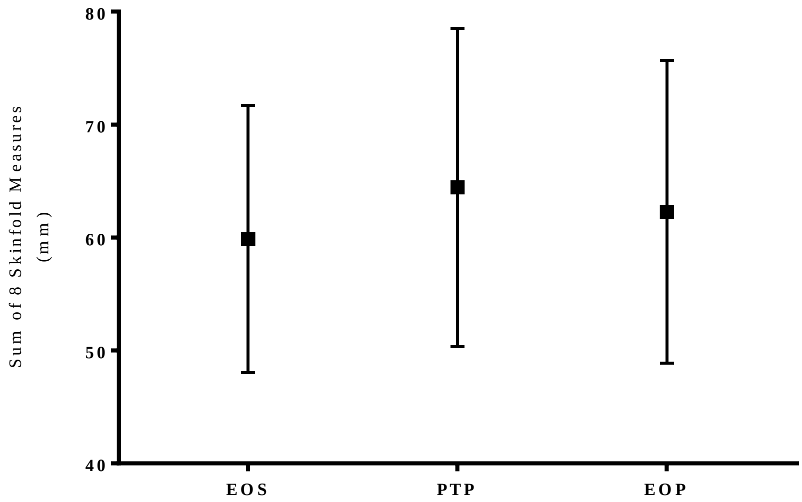

Figure 2.0 Sum of 8 skinfold measurements for EOS, PTP and EOP

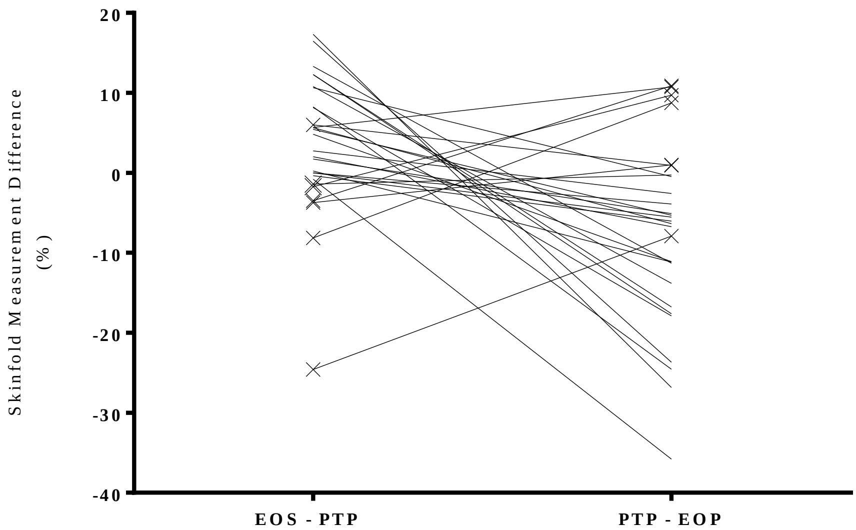

Figure 2.1 Individual player body fat per cent change between EOS to PTP and PTP to EOP ('X' signifies greater off-season change)

2.3.2 Physiological Measures

Laboratory based assessments, including cardio-respiratory step-test and $\dot{V}O_{2max}$ protocols, were completed by 39 elite outfield male soccer players (Appendix VI and Table 2.4). A total of eleven subjects further completed all three test occasions, with the lowest aerobic capacity ($\dot{V}O_{2max}$) results found PTP (56.9 ± 6.5 $ml \cdot kg^{-1} \cdot min^{1}$). This was found to be similar to EOS results observed (55.5 ± 4.8 $ml \cdot kg^{-1} \cdot min^{-1}$). Measurements at EOP (59.9 ± 6.1 $ml \cdot kg^{-1} \cdot min^{-1}$) were considerably higher than PTP and EOS (8.1% and 8.4% respectively), represented in figure 2.2. The EOP measurements were significantly higher than those at EOS ($r = 0.70$, $R^2 = 0.32$; $p < 0.01$).

Table 2.4 A table representing Absolute and Relative $\dot{V}O_{2max}$ and Maximal Heart Rate mean ± standard deviation values EOS, PTP and EOP

	Subjects	Absolute $\dot{V}O_{2\ max}$ (l·min)	Relative $\dot{V}O_{2\ max}$ ($ml \cdot kg^{-1} \cdot min^{-1}$)	Max HR (bpm)
May	n = 34	5.00 ± 1.17	55.5 ± 4.8	195 ± 13
July	n = 27	4.59 ± 0.85	58.1 ± 8.1	195 ± 18
August	n = 16	5.25 ± 1.09	63.9 ± 8.9	196 ± 18

*Note: mean values represented are for all subjects, not simply the n=11 participants assessed over all three time periods

The $\dot{V}O_{2max}$ individual variation results are demonstrated in figure 2.3 and Appendix XVIII. The effect size calculated between EOS and PTP was small (-0.25) and moderate between PTP and EOP (-0.48). A large effect size calculated between EOS and EOP (-0.80). Total results and statistical values from cardio-respiratory assessments conducted can be found in Appendix VI, Appendix VII and Appendix VIII.

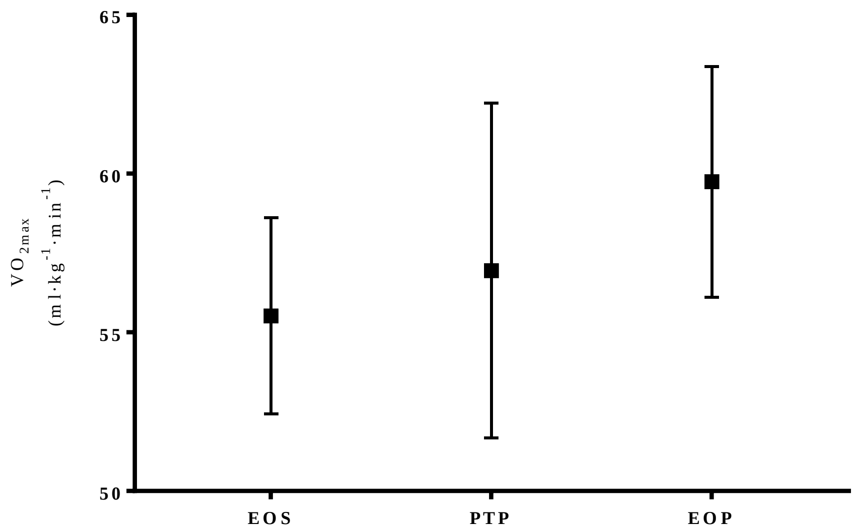

Figure 2.2 $\dot{V}O_{2max}$ (ml·kg^{-1}·min^{-1}) results EOS, PTP and EOP

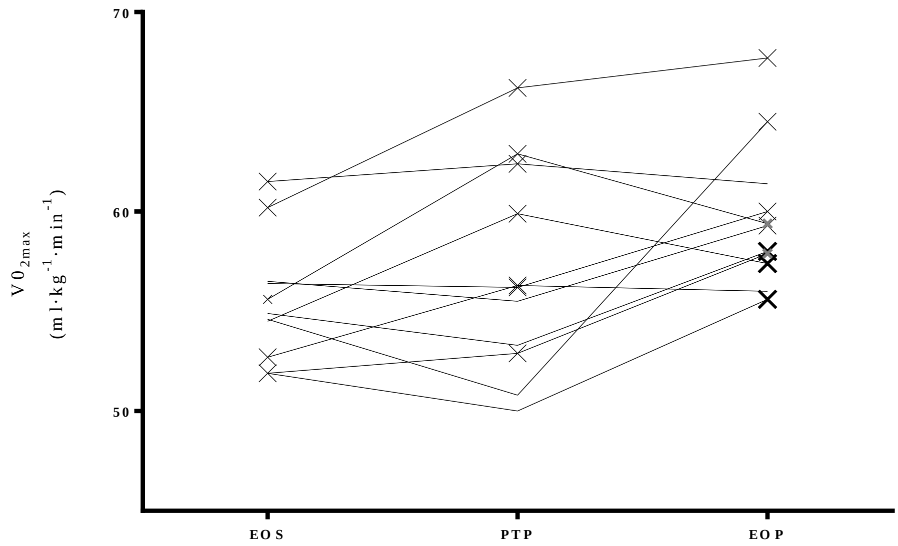

Figure 2.3 Individual player aerobic capacity change between EOS, PTP and EOP (‘X’ signifies $\dot{V}O_{2max}$ increase)

2.4 Discussion

2.4.1 Anthropometric Findings and Discussion

The measurements acquired during the current study were taken at specific time-periods in order to specifically investigate and establish elite male soccer player body composition adaptations over the off-season and pre-season. The skinfold measurement results demonstrated a trend, but not significant difference, between the three time periods, with the lowest results observed EOS and highest results found PTP, followed by EOP (section 2.3.1). These values are higher than previously found with International soccer players (Casajús and Aragonés, 1993., cited by Casajús, 2001) and Olympic soccer players (Novack et al, 1972; cited by Cater and Yuhasz, 1984) where actual total skinfold values were reported as 50 mm and 46.4 mm respectively. However, this could be owing to numerous factors, including a different number of skinfold sites measured, inter-practitioner variation between anthropometrists, ethnicity of the players measured as well as time of the season the skinfolds were obtained.

Comparison made between skinfold measurement values from different research groups is problematic, particularly owing to inter-practitioner variation (Hume and Marfell-Jones, 2008), values provided having already been converted to per cent (without raw skinfold data shared) (Arnason et al, 2004; Casajús, 2001; Kalapotharakos et al, 2011), as well as on occasion not citing the conversion equation used (Bangsbo et al, 1994; Boone et al, 2012). These factors add imprecision, making presumed associations less feasible. Furthermore, alternative methods of analysis (e.g., DEXA and BIA) clearly do not produce the same outcome measures as skinfolds, so comparison should be avoided, and even within skinfold measurement, a variation on the skinfold sites or number of skinfolds obtained makes direct raw value relationships impossible to distinguish.

Therefore, values converted into per cent (using the equation by Withers et al, 1987) from the current research undertaken were similar to Icelandic elite (10.5%; Arnason et al, 2004) and Danish elite (10.6%; Bangsbo et al, 1994) soccer players for EOS and EOP with PTP values (section 2.3.1) more comparable to body composition measures previously found with Saudi elite players (Al-Hazzaa et al, 2001). This latter value falling outside of the 11.5-12.0% maximum body fat per cent for soccer players, suggested by Gil and colleagues (2007).

A handful of studies exist where the anthropometric values of elite soccer players have been evaluated on repeated occasions. Casajús and colleagues (2001) assessed male players from the Spanish First Division (La Liga) after the completion of pre-season (September) and mid-season (February). Although the mid-season measure is of interest, particularly occurring after their winter break, only the first measure (8.6 ± 0.91%) can be related to the post- pre-season measure in the current study. Similar research conducted with a professional Greek soccer team (Kalapotharakos et al, 2011) did assess within-subject variation at the start of pre-season and EOP, as well as mid-season. A greater variation was noted as a result of pre-season training, from 10.5 ± 2.5% to 8.7 ± 1.8%, than the present research (section 2.3.1). This may be explained by the extended pre-season period in the National Greek Division (July to October, compared with July to August in the English domestic leagues). Additionally, the increase in body fat per cent observed within the present study might be attributed to a rise in skinfold measurement values for a select group of players (Appendix XVI; figure 2.1), which has in turn skewed the mean and broadened the standard deviation. The third longitudinal study worthy of reflection, with the present research in mind, was conducted with a club in the Football League Championship (Clark et al, 2008), where key time periods throughout the season mirror those currently investigated. However, although similarly three test occasions occurred, these were at the start of pre-season, mid-season and end of the season, conducted over three consecutive seasons. This research provides particular insight in relation to the existing study's 'off-season' values, where the two consecutive EOS and PTP values were higher than those observed within the present study (EOS, 11.6 ± 2.6% and 11.5 ± 2.9%, vs. 10.1 ± 2.0%; PTP, 12.8 ±

3.0 and 11.8 ± 2.3, vs. 10.4 ± 2.1). The difference between these measurements, demonstrating the off-season change, was found to be more pronounced with the Championship players, 0.75% ± 0.5% compared with 0.3 ± 0.1%. It's worth noting that Clark and colleagues (2008) in this example used Bioelectrical Impedance Analysis for the assessment of body fat, and despite closely standardising hydration, this method lacks sensitivity required to identify training-induced changes in body composition (Sillanpää et al, 2013) and can result in an overestimation of fat mass (Grund et al, 2001).

Despite a clear trend emerging with the current research undertaken, demonstrated by figure 2.0, a lack of definitive significance may be due to the large individual variation between players, as previously alluded to. This is highlighted when the per cent difference is calculated between May and July (EOS and PTP), July and August (PTP and EOP) and finally May and August (EOS and EOP; illustrating the body composition adaptations occurring throughout the season). Figure 2.1 displays these relationships between body fat fluctuations, where a clear trend is highlighted, as well as emphasising individual subjects who display contrary results. Interestingly, many of the players highlighted on figure 2.1 (4 of 7) that oppose the perceived trend (indicated by dashed lines) are the only individuals to also have lost per cent body fat during the 'off-season' or maintained body fat over this period (2 of 7). In the absence of a detailed synopsis of these player's, and the overall squad's, off-season conditioning programming, nutritional intake or injury profile over these time periods, a rationale is difficult to distinguish.

2.4.2 Physiological Findings and Discussion

The present research provides direct evidence that, for professional English Premier League soccer players, maximal aerobic capacities observed after pre-season are significantly greater than the preceding post-season results (section 2.3.2). This was not found within semi-professional soccer where measurements were taken indirectly using the MSFT (Léger et al, 1982), and instead found to be comparative between these time-periods (58±1.9 vs. 58±1.6 $ml \cdot kg^{-1} \cdot min^{-1}$) (Caldwell and Peters, 2009). These results suggest that aerobic capacity declines over the course of the season, which is further substantiated when maximal aerobic capacity scores are examined (figure 2.3) and the physiological performances of 55% of the subjects (6 of 11) increase during the off-season period. This is somewhat unexpected given the general assumption is that physical attributes decline during the off-season, as well as previous research providing opposing results (Caldwall and Peters, 2009; Clark et al, 2008).

This maintenance of aerobic capacity observed during the off-season in the current study (section 2.3.2), or even increase when individual subject data is studied (figure 2.3), could be attributed to a number of factors;

1. The pre-season preparation for the preceding year's pre-season preparations may have been a lower volume or intensity, with lower overall aerobic base-line values established, which were subsequently maintained throughout the season. Despite the length of the season (over 9 months) it is hypothesised that maintenance of pre-season physiological assets built is feasible (Caldwell and Peters, 2009).
    a. Additionally, the off-season conditioning programme set may have been highly effective and well adhered to by subjects involved with the current study.
2. Substantial fixture congestion mid-season through to the end of the season could limit the opportunities to maintain physiological capabilities (Reilly et al, 2006). Therefore, the aerobic capacity base-line attained PTP may have been significantly decreased by EOS.
    a. Furthermore, the off-season training during the current study may have been effective and followed closely by subjects involved; however the predominant factor for aerobic maintenance (or even increase) off-season could have been the cessation of disproportionate continuous load and the resulting dissipation of residual fatigue accumulation. To clarify, the players could have been experiencing various extents of over-training, thus further adaption or supercompensation occurring, once the season had come to a close (Verkhoshansky and Siff, 2006; Plisk and Stone, 2003).

Unfortunately the present study cannot provide any definitive answers to the above points, given that no testing was performed the previous season, and no access was provided to the player loading data throughout the season (such as global positioning system, heart rate, or TRIMP data (Impellizzeri et al, 2004; Stagno et al, 2007)). Moreover, no training load publications appear to exist longitudinally within soccer, from which similarities might be determined.

An alternative explanation could also be that the aerobic capacity levels demonstrated at the end of the season more suitably represent the actual values required to be repeatedly ‘match fit’ and the demands of the game, rather than potentially inflated values that could be incorrectly facilitated by fitness and coaching staff. Instead, it could be an alternate multifactorial attribute (such as anaerobic capabilities) that naturally dominates when match play is the overriding form of conditioning. This is supported by a greater prevalence of high intensity focus within the literature, both within games (Abt and Lovell, 2009; Bradley et al, 2009; Di Salvo, 2009; Reilly, 1997) and emphasis toward anaerobic conditioning in training (DuPont et al, 2004; Kotzamanidis et al, 2005; Sporis et al, 2008). Despite this, a certain level of aerobic conditioning would still be necessary, in order to recover adequately from intermittent high intensity bouts and avoid a detrimental onset of fatigue. Conversely, all teams within the competitive league could experience a periodic rise, plateau and eventual decrease in physical capacity as the season continues. This could subsequently cause a spiral effect on overall match demands throughout the EPL season, given that total distance, high-intensity running and very high-intensity running are influenced by the activity profile of the opposing team (Rampinini et al, 2007).

In general, the aerobic capacity results attained PTP were similar to other male elite European values during the same period (Arnason et al, 2004; Clark et al, 2008), which Clark et al (2008) also found as the lowest measure when comparing prior to pre-season, mid-season and end of the season, over three consecutive seasons. The present research EOP measures obtained were also comparable to similar elite soccer players during that phase (section 2.3.2) (Casajús, 2001, 65.5 $ml \cdot kg^{-1} \cdot min^{-1}$; Kalapotharakos et al, 2011, 58.1 ± 3.1 $ml \cdot kg^{-1} \cdot min^{-1}$), as well as

EOS (55.5 ± 4.8 $ml \cdot kg^{-1} \cdot min^{-1}$) (Caldwell and Peters, 2009, 58 ± 1.9 $ml \cdot kg^{-1} \cdot min^{-1}$). A minority of studies were either non-specific about the exact time period when the testing was conducted (Wisløff et al, 1998), making associations difficult to determine, or fail to provide the actual results (Clark et al, 2008). The only genuine comparison of variation is feasible with Caldwell and Peters (2009), despite having not directly measured aerobic capacity, where testing also occurred at the EOS, PTP and the EOP. Contradictory to the present study, the EOS and EOP results were equivalent (58 ± 1.9 and 58 ± 2.2 $ml \cdot kg^{-1} \cdot min^{-1}$, respectively) and pre-season adaptations were not as pronounced, with 3% versus 5% change measured (56 ± 1.2 and 58 ± 1.9; difference observed by Caldwell and Peters (2009) prior to pre-season and end of pre-season, compared with the current research (section 2.3.2). The figure of 60 $ml \cdot kg^{-1} \cdot min^{-1}$, stipulated by some researchers as the lowest threshold aerobic capacity value for soccer players (Reilly et al, 2000; Stølen et al, 2005), was essentially reached by the elite male soccer players in this study at the EOP, but not at the EOS or PTP. This position stand for a minimum threshold therefore may require specifying to 'in-season' aerobic capacity requirements. Greater clarity on guidelines for not only key time points within the season would be advantageous.

2.4.3 Future Anthropometric Study Recommendations

The following topics of further research would be advantageous in terms of enhancing knowledge and application of body composition variation and ideals within male elite soccer;

- A greater research base of repeated seasons, within-subject fluctuation of body composition, particularly using a repeatable and sensitive measure (such as DEXA or skinfold measurement with a well-qualified anthropometrist). Furthermore, ensuring assessments are performed at the end of the season, prior to the start of pre-season and at the end of pre-season, to note individual response to potential de-training and adaptation.
- Measurements acquired at regular intervals throughout the season, whilst concurrently monitoring training load (as well as nutritional intake where

possible) and number of fixtures played, would be of interest to note whether body composition has a gradual decline or maintenance throughout the long periods of repeated competition.

– A greater focus on nutritional or training prescription adjustments to compensate for time whilst injured, or periods of reduced training load (for example not getting a starting eleven on match days, transitioning from playing regularly in the academy to being on the senior team bench or a different coach with ulterior strategies for training, for example).
– Monitoring of body composition aligned with indicators of infections; whether the body fat of individuals could or should be gauged on their immunity. In other words, individual players should be given a ‘lower limit’ to deter the onset of illness.
– If performance measures, such as global positioning system training statistics (accelerations, decelerations, distance travelled, high intensity distance travelled, for instance), ProZone match analysis (technical attributes; such as passing accuracy and physical attributes; such as high intensity efforts per minute) and self-reported measures of performance, can be used longitudinally with body fat results to determine a more bespoke approach to individual’s ideal composition. This scientific and statistical approach could build on the work of Arnason and colleagues (2004), around team success and measurement of skinfolds, and may help to dispel some blanketed stipulations that exist (anecdotally) of body fat from coaches and sometimes medical staff that still exists at some professional soccer clubs. For instance, every player stipulated to have a body fat of maximum 10%.
– Either a larger body of dedicated research investigating ethnicity differences in body composition measurements, adding to the findings of Sutton et al (2009), or simply an appreciation of recording and stating the ethnicity of subjects involved within studies, allowing associations and relationships to be observed over time. Although some ethnicity origins might be assumed by some papers stating the national team measured, such as Saudi elite (Al-Hazzaa et al, 2001) or Danish elite (Bangsbo et al, 1994) male soccer players,

many publications are based within club environments with a variety of nationalities, such as the English Premier League (Strudwick et al (2012).

2.4.4 Future Physiological Study Recommendations

The below points are topics which were either highlighted throughout the current research undertaken, or identified within contemporary literature as areas of elite soccer physiology which could be further explored to enhance understanding and/or application;

- The demands of soccer within the professional game appear to be ever evolving (Reilly and Thomas, 1976; O'Donoghue, 2002; Bradley et al, 2009), with a shifting emphasis toward repeated high intensity activities requiring anaerobic metabolic pathways (Abt and Lovell, 2009; Di Salvo, 2009; Reilly, 1997). Despite it being acknowledged that a substantial aerobic base is still imperative to preserve successful performance, the balance of these attributes (particularly position specific) is yet to be quantified.
- The short-term and longitudinal accumulating impact of increased fixtures (including league fixtures, European fixtures and national cup competitions, such as the FA Cup or community shield) on maximal aerobic capacity. Additionally, mechanisms of effective training interventions that successfully maintain aerobic capabilities; whilst not substantially increasing the weekly training load. Potential examples have been explored, including small-sided games (Owen et al, 2012), repeated hypoxic sprints (Bowtell et al, 2013) and under-water running (Takahashi et al, 2006).
- Despite directly measured submaximal and maximal aerobic capacity measures recorded from many European soccer national teams and first division teams (Table 2.1), no examples exist from the EPL. This may be of interest due to the match demands of leagues abroad being less than those experienced in the EPL (Drust et al, 1998; Rienzi et al, 2000). These results may be similar to those identified previously in the English Championship (Clark et al, 1998), although a significantly more condensed schedule could modify the physiological attributes detected in comparison to the EPL.

– A greater volume of publications originating from professional soccer would be advantageous. In particular, investigating the impact of strategies employed during the off-season and subsequent pre-season would have applied advantages, due to the general lack of literature during these periods of the macro-cycle. Currently there is just one paper that has focused on the physiological impact of post-season, pre-season and post-season (Caldwall and Peters, 2009), previous to the present study, and this was indirectly measuring using the MSFT (Léger et al, 1982) with semi-professional soccer players.

2.5 Conclusion

The current study aimed to investigate the specific anthropometric and aerobic characteristics of elite male soccer players during the EPL off-season. The players were assessed on three occasions, End of Season (EOS), Prior to Pre-season (PTP) and Post Pre-season (PPS), to determine maximal aerobic capacity and estimate body fat.

The lowest values for both physical characteristics were found at EOS, suggesting to a decline in aerobic capacity occurs over a competitive season. Additionally, these results signify that the physical demands imposed during the season have a greater impact on body composition than observed after pre-season. The impact of pre-season training was as expected, with an 8% increase in aerobic capacity and 6% decrease in sum of eight skinfold body fat results.

In summary, this study has concluded that it is likely aerobic capacity declines over an EPL competitive season. These findings not only impact practice, to better investigate novel methods where aerobic capacity might be optimised and maintained, but could also provide evidence toward an EPL re-structure and introduction of a mid-season break.

CHAPTER III THE ANTHROPOMETRIC, REPEAT SPRINT AND MATCH PERFORMANCE RELATIONSHIP IN ELITE FEMALE SOCCER PLAYERS (STUDY B)

3.0 Introduction

Prior to the most recent review by Datson et al (2014), the last physiological overview of female soccer was over twenty years earlier (Davis and Brewer, 1993). The game has progressed a huge extent over that time, although the scientific research contributions remain relatively sparse. The largest influence has been from one Scandinavian research group (Andersson et al, 2007; Andersson et al, 2008; Andersson et al, 2009; Andersson et al, 2010; Krustrup et al, 2005; Krustrup et al, 2010), with only a handful of additions from the other largest soccer nations (Davis et al, 1992; Davis and Brewer, 1993; Holmes, 2002; Vescovi et al, 2011). Despite the science support for top female teams anecdotally becoming more prolific over this time, a greater level of collaboration, knowledge sharing and ultimately publication is necessary to continue the physical performance progression of the game.

This thesis chapter therefore aims to address specific sections of the significant lack of literature available on elite female soccer players, providing baseline anthropometric characteristics, RSA assessment values and match demands (specifically focused around high intensity bouts). In addition, the ability to prevent fatigue and sustain multiple high intensity outputs has been prominent with elite male soccer literature (Balsom, 1990; Boone et al., 2012; Chamari et al, 2004; Mohr et al, 2003), yet no RSA research examples exist with elite female players and furthermore, no studies have identified whether RSA assessments sensitively distinguish between repeated high intensity output abilities during match play in female soccer. This research additionally plans to identify whether

RSA values in female players correspond to match-based high intensity activity. This adds significant value to the practical application of this assessment, contributing to the justification of its use (or disuse) with limited time and resources in the field. This study also adds unique data to the overall scientific body of literature, with only one other study in elite male soccer investigating eligibility of this assessment alongside match-based activities (Rampinini et al, 2007).

3.1 Review of Literature

The underpinning scientific information available within elite female soccer has progressed considerably over the last decade, concurrent with the marked increase in professionalism of the game (Datson et al, 2014). Paralleled with these advances, the physical attributes of players have undoubtedly developed. The clearest example of this is the body fat composition of elite female soccer players, previously averaging twenty two per cent (Colquhoun and Chad, 1986; Withers et al, 1987; Jenson and Larsson, 1989; Davis and Brewer, 1993) compared with modern player values averaging fifteen per cent (Krustrup et al, 2005; Mujika et al, 2009). This distinct step-change is more difficult to distinguish for physical capacity within competitive match play, as earlier studies are not available, unlike elite male soccer (Reilly and Thomas, 1976) and only became prominent more recently (Andersson et al, 2007; Krustrup et al, 2005). The scenario is similar, if not more exaggerated, within repeat sprint ability (RSA) assessment where the justification (Stolen et al, 2005; Wragg et al, 2000) and protocol design (Balsom, 1990; Bangsbo, 1994; Malomski, 1993) have been established within male soccer, but only later leveraged within female soccer and to a much lesser extent (Krustrup et al, 2010; Taylor et al, 2012). This disparity of published work isn’t isolated to these examples; it is evident throughout scientific literature where female soccer is concerned.

Currently there are a few studies which have observed anthropometric and physical capabilities within female soccer (Can et al, 2004; Sedano et al, 2009; Polman et al, 2004), including aerobic capacity (Polman et al, 2004), but none concerning RSA. Additionally, despite the contemporary emphasis on high intensity match performance (Bradley et al, 2009; Di Slavo et al, 2009; Andersson et al, 2010), just a single study has investigated whether RSA can successfully differentiate players’ abilities to who can repeat high intensity efforts (Rampinini et al, 2007). This research was conducted with male amateur players and currently no studies have focused on RSA and high intensity output ability within elite females. The purpose of this literature review therefore is to not only investigate the aforementioned isolated research within body composition, RSA and match-based high intensity activities, but furthermore, the associations previously found between these factors.

3.1.1 Anthropometric Measures

In relation to elite female soccer, the literature is far less diverse in comparison to elite male player data, with body mass and height providing the majority of anthropometric measures collated whilst gathering other physical-based test data (Haugen et al, 2012; Hewitt et al, 2007; Vescovi, 2006, for example). Davis and Brewer (1993) review some of the first body fat measurements undertaken with elite female soccer players, including an examples from Australia (Colquhoun and Chad, 1986; Withers et al, 1987) and the England Women's squad, which describes the change found pre- and post- a twelve month training programme (21.5 and 21.1% respectively; Davis et al, 1992). Despite these studies providing a step-change in terms of the measurement of female soccer players, no context was given in relation to training methods, dietary intake or association with performance; the detail of which would have had a positive impact on the application of soccer science within the female game.

Since these initial studies, female soccer has progressed significantly on a global scale, in particular in the USA (Women's Professional Soccer league inception in 2009, replaced by the National Women's Soccer League in 2013) and in Europe with the UEFA Women's Champions League (re-branded in 2009, to become more aligned with the men's UEFA Champions League) dominated in the main by Germany, Sweden and France. Progression has also occurred in England with the Women's Super League (WSL) set-up by The Football Association in 2011. This on-going frame-work expansion and financial support has enabled increasing professionalism of the game, allowing more advanced training practices and expertise involvement, positively impacting the physiology and body composition of the female players. This is emphasised by Jenson and Larsson (1992) who supplemented the Danish National team's training for a year and found significant anthropometric and physiological changes, which they concluded was also due to a change of attitude. This evolution is demonstrated in Table 3.0, where the body fat of International and first domestic league standard female players is highlighted. Meanwhile, other female sports were also progressing rapidly and documenting useful body composition comparisons, particularly in intermittent team sports (Gabbett et al, 2007; Geithner et al, 2006; Suarez-Arronez et al, 2012).

Table 3.0 Anthropometric profile of elite female soccer players

Study	Subjects	Method	Level / Country	Body Mass (kg)	Stature (cm)	Body Fat (%)
Colquhoun and Chad (1986)	n = 10	HSW**	Australian International	55.4 ± 6.5	158.1 ± 5.7	20.8 ± 4.7
Withers et al (1987)	n = 11	HSW**	Australian International	61.2 ± 8.6	164.9 ± 5.6	22.0 ± 6.8
Jenson and Larsson (1989)	n = 14	n/a	Danish National	63.2 ± 9.8	169.0 ± 10.0	22.3 ± 4.1
Davis and Brewer (1992)	n = 14	SF (4)*	England International	60.8 ± 5.2	166.0 ± 6.1	21.5****
Krustrup et al (2005)	n = 14	n/a	Elite Danish League	58.5 ± 10.9	167.0 ± 12.0	14.6 ± 6.3
Mujika et al (2009)	n = 17	SF (6)*	Spanish Super Liga	56.8 ± 5.7	165.0 ± 4.0	15.61***

* SF signifies Skin Fold Measure (number of site locations) ** HSW signifies Hydrostatic Weighing
*** Only sum of skinfold provided (74.4mm); converted into per cent body fat using Yuhasz (1966) equation
**** No S.D provided

To date, and to the best of this author's knowledge, there is no review that adequately summarises the body composition of elite female soccer players. Whilst undertaking a review of elite male soccer anthropometrics, Reilly et al (2000) described female soccer as having too little information in order for a review to be completed. Since this time however, there has been a further body of literature published, for instance differentiating the morphology of sedentary women, to those of professional female soccer players (Can et al, 2004) and where anthropometric characteristics can make the distinction between elite and non-elite players, where other performance parameters cannot (Sedano et al, 2009). These studies demonstrate that uniqueness exists with elite female soccer players' body composition and impact practice by detailing the profile of players at this level; providing target attributes for aspiring or development players and values of comparison between top flight players. Interestingly however, Juric and colleagues (2007) found that the morphology of female players didn't differ significantly between position, with the exception of the goalkeepers being the heaviest and tallest amongst the squad. Despite this progression, just one study examines the anthropometric changes occurring via differing conditioning programmes (Polman et al, 2004) and nutritional intervention (Cox et al, 2002).

Mujika and colleagues (2009) assessed the body composition of male and female, junior and senior soccer players all competing in their highest respective Spanish leagues. In addition to providing sum of six skinfold data for these groups, they also noted that body composition was related to Yo-Yo Intermittent Recovery Test-1 (Yo-Yo IRT-1) performance (an intermittent maximal aerobic field-based assessment; Bangsbo et al, 2008). This relationship of body composition with physical performance measures has been poorly documented in the literature to date, despite anecdotally a large emphasis often put on fat percentage margins within elite soccer. A greater number of interrelated studies, not only with isolated tests but also on pitch performance measures, could build a clearer picture for practitioners and support rationale for body composition adjustments, but also help toward creating a lower limit for body fat which is missing from both male and female literature. This is perhaps particularly pertinent for female players due to risks of female athlete triad (Nattiv et al, 2007; Torstveit et al, 2005).

Additionally, the female game only appears to have progressed significantly in the last decade, including from a body composition perspective (Table 3.0), and upper limit guidelines that have been suggested within elite male soccer literature (Gil et al, 2007; Sutton et al, 2009) are yet to be established. This would be a progressive step for practitioners to better understand whether the players they are advising are within an acceptable range for successful performance, ahead of providing individualised guidelines.

3.1.2 Repeat Sprint Ability

The premise of assessing repeat sprint ability (RSA) as an anaerobic representation of intermittent sport scenarios has a strong rationale. In previous years, the assessment criteria for team sports has been centred around aerobic capacity measures, such as continuous running (Raven et al, 1976), laboratory based treadmill protocols (White et al, 1988), continuous field-based assessments with increasing speed (Léger and Lambert, 1982), intermittent field-based assessments increasing in speed with rest periods (Bangsbo et al, 2008; Krustrup et al, 2003) and one assessment which replicates match activities, such as walking, jogging, cruising and active recovery periods (Nicholas et al, 2000). However, these assessments only reflect a proportion of the physical performance requirements of soccer. Despite aerobic metabolism providing the largest energy contribution during soccer matches (Reilly, 1997), it has been suggested that aerobic capabilities are simply a baseline commodity in the fitness portfolio, which support recovery from match-defining anaerobic efforts (Stolen et al, 2005; Wragg et al, 2000). Some of the aforementioned protocols do in fact have anaerobic elements, but none of which specifically isolate and overload that physiological pathway.

The actual match activity contribution from repeated sprints may have also developed over time within male soccer, with total match distance covered remaining relatively consistent (8.7 ± 1.0 km vs. 10.7 ± 1.0 km; Reilly, 1996 vs. Bradley et al 2009), but low intensity to high intensity effort ratios increasing in frequency (2:1 vs. 1.6:1 respectively, Reilly and Thomas, 1976; Bloomfield et al, 2010). This preceding work: rest ratio literature is not readily available within female soccer, with the possible exception of unpublished data by Ekblom and Aginger, reported by Davis and Brewer (1993), on the Swedish women's National League squad. The summary included average total distance (8471 ± 2.2 km) and average sprint distance travelled (14.9 ± 5.6m), however no repeat sprint specifics. These details are of interest in terms of distinguishing how the game has evolved when compared with recent match activity outputs, but also had the potential to significantly impact practice by clearly identifying match distance demands, but also providing speed durations and recovery periods. The importance of this is demonstrated when comparing the intensity of play between domestic and international competition within female soccer (Andersson et al, 2007), where research can then provide a platform from which National coaches can tailor the conditioning of players toward the most demanding games they are likely to encounter. This need for this research and specific conditioning is further emphasised when analysing national and international elite female games in Australia (Gabbett et al, 2013), where the players were found to increase the recovery period between repeat sprint efforts toward the end of a game. The average sprint duration in RSA bouts was also found to be greater during international fixtures. Continued research into female soccer, from development to senior, national to international, would support the further progression of soccer science and better inform practitioners, in order to keep optimising the conditioning of players.

Literature surrounding female soccer match analysis started from 2002 (Holmes, 2002) and became more prolific from 2005 onwards (Krustrup et al, 2005; Anderson et al, 2007; Scott and Drust, 2007; Hewitt et al, 2007). Contemporary top-flight domestic players have been found to spend 2.5 ± 2.5 minutes (mean ± S.D) between sprints during games, categorised as locomotor activities ≥ 18 km·hr (Vescovi, 2012). Although both male and female match activity studies provide good insight and application to better inform training, comparison of research is also difficult or ill-advised due to varying categories of speed thresholds, methods of match-analysis, validity and repeatability of match analysis methods and high-speed activities varying significantly match-to-match (Gregson et al, 2010).

Isolated sprint assessments are represented more frequently within the literature, in male (Haugen et al, 2013; Maio Alves et al, 2010; Chelly et al 2010; for example) and female soccer (Andersson et al, 2008; Haugen et al, 2012; Vescovi et al, 2011; for example), with repeated sprint testing less predominant. In terms of measurement of RSA, there are a variety of protocols reported, which include; 5 x 10m shuttles completed as quickly as possible with no recovery periods (Boone et al., 2012), 3 x 30m sprints with 3 minutes recovery between bouts (Chamari et al, 2004), 20 x 10 metres with 42 seconds active recovery periods (Balsom, 1990) and 15 x 30 metre sprints with 5 secs recovery, a 30 minute break, and then repeated (Malomski, 1993). Svensson and Drust (2005) describe a test involving 7 x 35 metre sprints with 25 secs recovery as one of the most commonly performed, designed by Bangsbo (1994) with reliability established by Wragg and colleagues (2000). The suggested measures from this assessment are the fastest sprint time, mean sprint time and fatigue index score, which is calculated by subtracting the fastest time of the first two sprints from the slowest time for the last two sprints (a low score therefore, in all three measures taken, is advantageous). The most substantial guidance into choice of post-assessment analyses and fatigue calculation is provided by Glaister et al (2008), who critically evaluated eight possible formulas. They concluded that equation 3.0 was the most suitable as it demonstrated a good construct and logical validity, provided consistent reliability and considered data from each sprint.

Equation 3.0 Fatigue = the percentage decrement score

$$\text{Fatigue} = (100 \times (\text{total sprint time}^{*} \div \text{ideal sprint time}^{**})) - 100.$$

*Total sprint time = Sum of sprint times from all sprints
**Ideal sprint time = Number of sprints x the fastest sprint time

Despite this being found to be the best equation to best represent the sprints undertaken within the assessment (Glaister et al, 2008), the use of indexes or decrement scores have received some criticism (Hughes et al, 2006; Oliver et al, 2006). The potential argument against the use of a fatigue index is articulated best by Oliver (2013), who explains the lack of reliability of such a measure and the difficulty of interpretation for coaches.

Despite studies that have found higher standards of soccer perform more high intensity running than lower standards, in male (Krustrup et al, 2003; Mohr et al, 2003) and female soccer (Andersson et al, 2010), only one research example appears to have been conducted in conjunction with RSA related field-testing (Rampinini et al, 2007), with another measuring both, but providing no combined conclusions (Rebelo et al, 1998). Therefore, although the test may sensitively distinguish between elite and sub-elite (Reilly et al, 2000; Sampaio and Macas, 2003), seasonal variability (Taylor et al, 2012) and nutritional intervention (Cox et al, 2002), it's aptitude in relation to actual match performance is yet to be determined, particularly within female soccer. Despite it being well-known that anaerobic capabilities (Stolen et al, 2005) and repeat sprint performance (Mohr et al, 2003) are central attributes to soccer performance, if decisions are made regarding test scores attained, then specificity is required for this assessment to successfully isolate and reflect the physiological demands imposed. This is particularly pertinent owing to the potential sporadic nature of RSA within the elite female game, purported by Gabbett and colleagues (2013). In addition, due to the known repeated nature of this style of assessment, it is possible that player pacing will occur (Svensson and Drust, 2005). This pacing doesn't replicate the game, in terms of the unpredictable intermittent activity and response to cues, however this is also difficult to avoid during RSA assessment.

3.1.3 Match Demands

The large proportion of publications conducted that investigate activities and intensities within female soccer originate from Scandinavia (Andersson et al, 2007; Andersson et al, 2008; Andersson et al, 2009; Andersson et al, 2010; Krustrup et al, 2005; Krustrup et al, 2010), with a minority from Australia (Hewitt et al, 2007; Gabbett and Mulvey, 2008), USA (Mohr et al, 2008; Vescovi, 2012), Spain (Barbero-Álvarez et al, 2008) and England (Holmes, 2002). Despite the first assessments of men's soccer occurring in 1976 (Reilly and Thomas, 1976), match analysis of the female game has only been a focus more recently (Holmes, 2002).

Elite female soccer players have been found to cover similar total distances during domestic games (10.0 - 10.3 km) (Krustrup et al, 2005; Vescovi, 2012) as male counterparts (10.0 - 10.7 km) (Barros et al, 2007; Bradley et al, 2009); which is contradictory to the thoughts of Carling et al (2008) who concluded that less distance was covered in general. This may have been due to breadth of nationalities, international standings and date ranges included in the example papers, as well as providing no comparative male figures. Gabbett and Mulvey, (2008) provide a typical breakdown of this total distance, comprised of 15.7% standing, 50.1% walking, 26.7% jogging, 7.5% high-intensity running, 4.8% striding and 2.7% of time sprinting; involving in total 1,326 activity deviations throughout, corresponding to changes every ~4 secs during games (Mohr et al, 2008). Whilst evaluating the physical preparation of players, focus has been primarily around high intensity distance or high-speed distance travelled (Bradley et al, 2009; Di Salvo et al, 2009; Reilly, 1997), with lower intensity activities providing insight toward recovery periods for optimisation of training methods (Bangsbo et al, 2006) and specificity of testing (Drust et al, 2000; Krustrup et al, 2003; Nicholas et al, 2000). Although female players have been found to perform less high intensity distance than professional male players, this may be owing to absolute speed thresholds which are not appropriate or specific to individual player velocities (Gabbett, 2015), plus the physiological strain incurred has been found to be comparable (Krustrup et al, 2005; Kirkendall (2007). Although this suggests that the two gender competitions appear alike, inherent physiological characteristics appear to inhibit female players' work capacity. Establishing the differences that exist between male and female soccer physiology and performances allows a better understanding of the literature that can be used, transitioned or discarded between groups. Ideally, knowledge would be acquired that builds and bridges the current literature gap that exists between respective games. This would impact performance by enabling greater intelligence and specificity to the conditioning and preparation of female players.

The assessment of demands imposed during intermittent sports, particularly those involving predominant upper body movements (a consideration when working with goalkeepers) (Faccini and Monte, 1995; Smith, 1998), provides continued challenges. Notational analysis was first leveraged by coaches, and subsequently by medical and fitness staff, to determine technical/tactical and physical outcomes of matches - a cost-effective method still used widely in soccer (James, 2006). This technique may provide benefit where movement specifics or activities of one player are observed, such as post-intervention work (turning, body positions assumed, for example) or on return from injury (in terms of compensation or mechanical weaknesses identified). However, a crucial limitation is the inability to accurately evaluate individual and team work-rates, which was in part addressed by Reilly and Thomas (1976), and further developed by Bangsbo et al (1991), using video-tape recordings. This filming of individual players is from an elevated position, with a map of pre-determined pitch distances used as reference. This system of time motion analysis has since been replicated and adapted by numerous researchers of small-sided games (Dellal et al, 2012), futsal players (Barbero-Alvarez et al, 2008b), top-class referees (Catterall et al, 1993; Krustrup et al, 2002) and assessment of female soccer (Andersson et al, 2010; Gabbett and Mulvey, 2008; Krustrup et al, 2005). This background provides some insight to the progression of performance analysis in soccer, and male soccer in particular, spanning four decades (Reilly and Thomas, 1976).

Subsequent evolution of analysis within soccer has been in response to the growing professionalism and increasing demand for depth of information by clubs and international teams. Specifically regarding competitive match analysis, semi-automated multi-camera image recognition systems (such as; ProZone®, ProZone Sports Ltd, Leeds, UK; AMISCO Pro, Nice, France match analysis systems; Focus X2, Elite Sports Analysis, Delgaty Bay, Fife, UK; SportsCode, Sportstec, Warriewood, NSW, Australia) have grown rapidly in popularity and functionality, appealing to both coaching staff and sports scientists for their technical/tactical (James et al, 2004; Lago, 2007; Tenga et al, 2010) and physical outputs (Di Salvo et al, 2006; Randers et al, 2010). Similarly with all performance monitoring instruments, individualisation is crucial for valid, comparable and meaningful data to be obtained; for instance ProZone® typically supplies pre-determined locomotor activities for all players (Rampinini, 2007), although this has been found to substantially underestimate high intensity distances, when equated beside personalised physiologically determined thresholds (Abt and Lovell, 2009). These are particular obstacles which have been encountered and received particular attention within male soccer, although yet to be leveraged fully on a domestic or international stage within the female game.

A similar challenge exists when attempting to relate data collated via different methods of technology, such as match play statistics, using a semi-automated multi-camera image recognition system, and training distances, using Global Positioning System (GPS) technologies. This is common practice within elite male soccer (Osgnach et al, 2010), although direct comparison should not be made, due to the large variation between methods, in particular when relating sprint performance (~40% discrepancy) (Harley et al, 2011). However, using these derived figures with caution may be necessary, due to the absence of any interchangeable technology that is permitted during fixtures and provides accurate training and match-day statistics. In terms of comparative data between training and match-demands therefore, GPS devices have been used in Australian football (Gastin et al, 2013), rugby league (Gabbett et al, 2012) and rugby union (Hartwig et al, 2011; Venter et al, 2011), but no examples currently within either female or male soccer. This is likely due to the aforementioned restrictions, with the only opportunity to measure being friendly pre-season fixtures, pending permission granted from the attending referee. Despite these seemingly to provide worthy opportunities for comparison with training or in-season match demands, frequently games are held against lesser opponents, resulting in decreased work-rates (Folgado et al, 2014), and often within more physiologically challenging environments than typical league conditions (hot and humid locations, for instance), also resulting in a decreased level of intensity than habitual performances (Özgünen et al, 2010). This disparity of measurement technologies is unfortunate, particularly of late because the training demands for an EPL team have recently been quantified over a whole season (Malone et al, 2015) and this data only providing a proportion of the picture without the in-season match demands.

Despite the legislative and logistical challenges of GPS analysis (in terms of each player having to wear a device within a tailored vest or shirt), there have been some interesting studies undertaken, which also impact practice. In terms of male soccer, aside from velocity and movement patterns alone, examples include the effects of environmental conditions on thermal response and activity profiles (Özgünen et al, 2010) and impact of high and low carbohydrate diets on distance covered (Souglis et al, 2013). Female soccer however has been focused toward activity profiling, possibly due to a lack of historical underpinning studies available and secondly, teams typically do not have access to semi-automated multi-camera image recognition systems (or similar), meaning that manual single-camera analysis or GPS have been required to conduct the majority of the game-based research. Publications that have used GPS technology however, include the investigation into physical demands of young female soccer players (Barbero-Álvarez et al, 2008) and senior Australian player work-rates during an international tournament (Hewitt et al, 2007). A larger volume of literature in this area would be advantageous in terms of establishing a foundation of normative training values, which can better inform practice. At present, equipment like GPS is rarely used within female soccer, given staff expertise, time available and financial resources are a major limitation versus men's soccer. Therefore, conditioning parameters of distances and individualised high intensity repeated markers (demonstrated recently in research by Gabbett, 2015, for instance), would provide a platform from which targeted performance solution platforms can then be built, once it is possible for the technologies to become more prolific.

2.1.4 Literature Summary

The science supporting elite female soccer has advanced in the last decade (Datson et al, 2014) alongside improvements in match-based physical capabilities (Davis and Brewer, 1993; Vescovi, 2012) and body composition of elite female players (Table 3.0). Field-based testing methodologies however have changed over time, which makes identifying the progression of specific fitness attributes difficult to determine (Davis and Brewer, 1993; Bradley et al, 2012). These aspects represent a short history of science within the female game relative to male soccer (Thomas and Reilly, 1976), which is also reflected by the comparative lack of depth represented across the literature.

The ability to repeat high intensity efforts has been well documented (Bradley et al, 2009; Di Salvo et al, 2009; Reilly et al, 1997) and valued within male soccer (Mohr et al, 2003), however examples within female soccer are sparse (Andersson et al, 2010). For instance, studies have observed anthropometric characteristics aligned with physical capabilities (Can et al, 2004; Sedano et al, 2009; Polman et al, 2004) but none focused on RSA. Additionally, despite RSA now commonly used within the array of team assessments, no evidence is provided that this suitably reflects female match-day demands or capabilities. This research therefore has two primary objectives concerning the aforementioned gaps within the literature; 1. To investigate whether predicted body fat, using sum of eight skinfolds, is interrelated with players' ability to perform repeated sprints (RSA) and; 2. Explore if RSA field-testing results are associated with players' repeated high intensity efforts during match-play.

3.2 Methods

3.2.1 Participants

A total of eighteen elite semi-professional female soccer players (age, 30 ± 10 years; stretch stature, 1.69 ± 0.68 m; body mass, 64.6 ± 9.7 kg) were assessed at the start of pre-season, whilst preparing for competition within The FA WSL. The anthropometric and repeat sprint assessment were measured on one occasion, shortly after return from the off-season (February), with heart rate and global positioning system analysis of friendly matches also occurring during this time (one fixture at the end of January and four in February).

Prior to the commencement of testing, all participants were fully briefed on each element of the testing they were being asked to complete and reminded that they could withdraw at any point. It was explained that all information collected during the course of the research will be kept strictly confidential and all data anonymised (with only the medical team at the football club having access to the system of coding participants). Informed consent was obtained with gate-keeper permission from the First Team Manager.

3.2.2 Anthropometric Measures

The player anthropometric measures were assessed on arrival to the training ground in the evening, as this was the only time period possible. Body weight was determined using digital scales (Seca Scales; Hamburg, Germany) and recorded to the nearest 0.1 kg. Stature was taken as the maximum vertical distance from the floor to the vertex of the head. A second measurer was required to check the heels were not elevated whilst stretch force was applied by the anthropometrist, cupping the subjects head and providing firm traction alongside the mastoid processes. Body composition was assessed using skin fold callipers (Harpenden Skinfold Callipers; Cranlea, Birmingham, Great Britain) with measures obtained over eight locations; triceps, subscapular, biceps, iliac crest, supraspinale, abdominal, front thigh and medial calf. All anthropometric assessments were performed according to the procedures stipulated by the International Society for the Advancements of Kinanthropometry (Appendix III) by a professionally trained Kinanthropometrist.

3.2.3 Repeat Sprint Ability

The participants performed the repeat sprint ability assessment subsequent to completing all anthropometric measurements and shortly after a standardised warm-up routine was performed.

A total of seven repeated maximal velocity thirty metre sprints were executed, from which acceleration (five metres) was also determined. A total of twenty secs was given to complete each thirty metre effort and return to the start position (active recovery), which remained consistent regardless of the sprint time observed. Each participant was instructed to perform maximally through all three sets of gates and only slowing within the deceleration zone (figure 3.0).

At the start of the test and prior to each repetition, the participants were asked to place their front foot behind the marker (one metre before the first timing gate) and given a five second countdown.

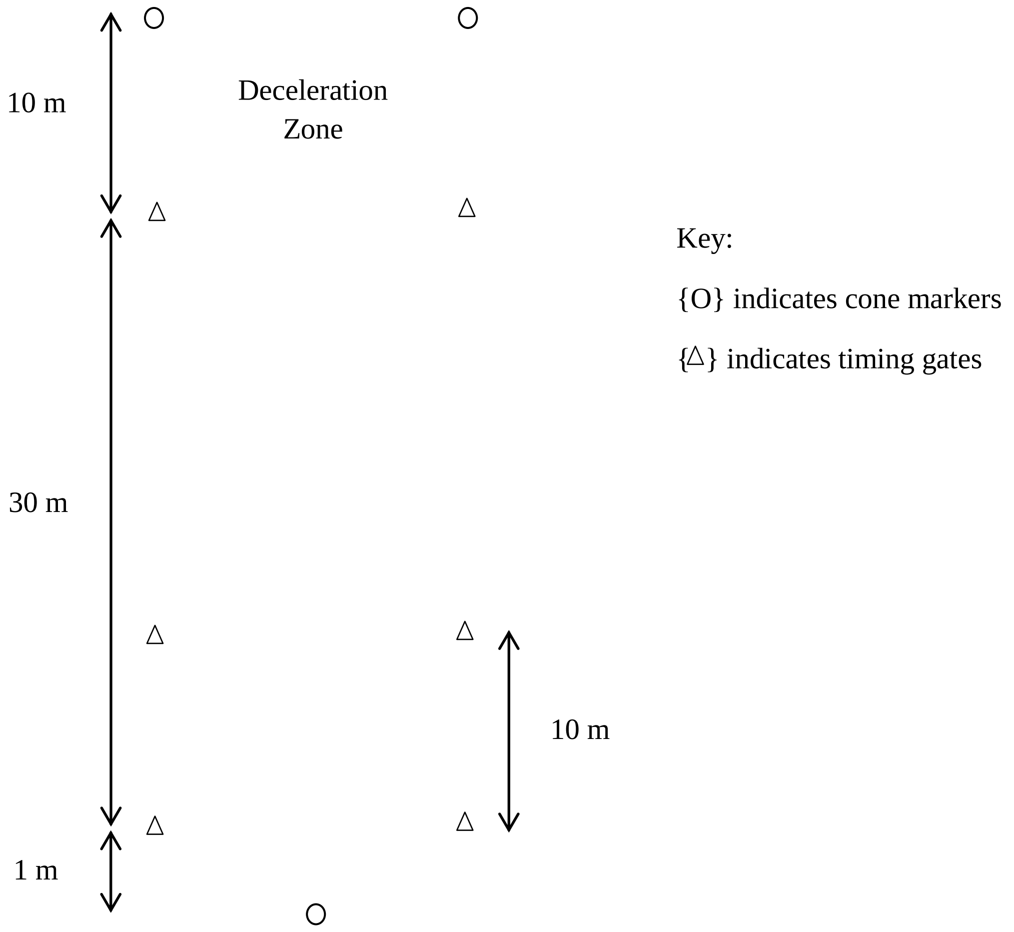

Figure 3.0 A diagram to represent the Repeat Sprint Ability assessment protocol

3.2.4 Match Demands

Analysis occurred during five pre-season fixtures (one at the end of January and four during February) in preparation for The FA WSL season. These were the only available opportunities for assessment of matches, as global positioning satellite system (GPS) devices and heart rate (HR) monitors and are forbidden during competitive League fixtures.

Activity profiles were intended to be measured using GPS devices (SPI 10, GPSports, Canberra, Australia) and analysed using proprietary software (GPSports Analysis v1.6, GPSports, Canberra, Australia) for all five friendly fixtures, however referee permission and equipment availability proved limiting.

Therefore, GPS devices were leveraged with two fixtures, and a team based heart rate monitoring system (Polar Team 2 Sport System, Polar Electro Oy, Finland) used as an alternative measure for work-rate performed for the remaining three fixtures.

The detail and range of information provided by the GPS technology system is substantial, therefore a set criterion of five output data measures were established;

1. Total distance covered during the match (m); excluding the warm-up and warm-down
2. Total distance covered per minute (metres per min (m·min)); total distance of the game divided by the number of minutes played by each participant
3. Total high intensity distance (m); also referred to as speed zone 5 (4.1 – 5.0 metres per second (m·s)) and speed zone 6 (≥ 5.1 m·s) combined
4. Total high intensity distance covered per minute (m·min); speed zones 5 and 6 combined and divided by the number of minutes played by each participant
5. Total high intensity entries per minute (entries·min); referring to the number of occasions in a minute a player reaches a speed equivalent to, or greater than, 4.1 m·s

Similarly, comprehensive feedback was available from the team based heart rate monitoring system, where time spent in each heart rate zone (zone 1; 50-59%, zone 2; 60-69%, zone 3; 70-79%, zone 4; 80-89%, zone 5; 90-100%) was recorded. These percentage values were based on each individual participant's heart rate maximum, estimated using the equation of 220 minus the individual's age (Astrand and Rodahl, 1977; Equation 3.1), in the absence of a maximal assessment undertaken and actual maximal heart rate values being recorded.

On arrival to the stadium, the starting ten outfield players were provided with their devices to be worn (either GPS device or heart rate strap). These were recorded throughout the warm-up period, first half and second half of each game.

3.3.4 Statistical Analyses

The data set collated was over one field testing occasion (February) and five pre-season fixtures (January and February) and analysed in total initially using a correlation matrix, discounting missing data sets and highlighting areas of significance (accepted at the level of $p < 0.05$). A paired T-Test (independent samples by variables) with Levene's post-hoc analysis was used to determine significance between two separate variables.

All data was analysed using a statistical software package (Statistica 8, StatSoft Inc. Oklahoma 74104, USA).

3.3 Results

3.3.1 Anthropometric Measures

The sum of eight skin fold measurement totals demonstrated a significant relationship with repeat sprint ability (r = 0.71, R^2 = 0.32; $p < 0.01$). The mean and total thirty metre sprints are represented by figure 3.1 and appendix XIII. No significant was found between anthropetric values and mean five metre ($p > 0.05$) or total five metre ($p > 0.05$) repeated acceleration scores (appendix XII).

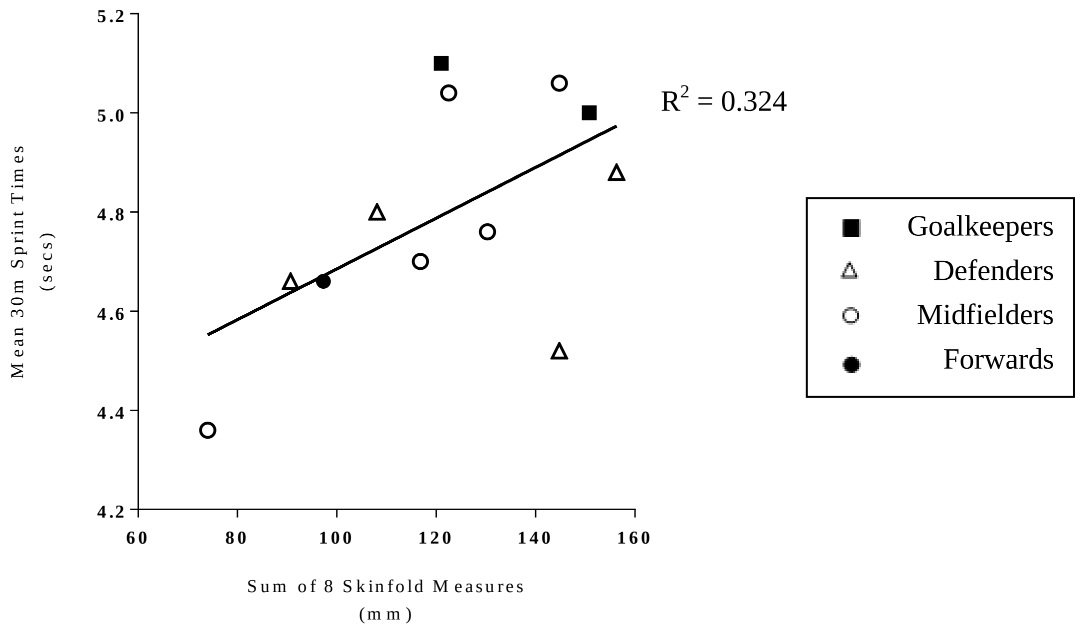

Figure 3.1 A scatterplot demonstrating the relationship between sum of eight skinfold measures (mm) and mean thirty metre sprint times (secs) (n=12)

Anthropometric measures were taken from eighteen subjects across all positions within the squad; goalkeepers (n = 2), defenders (n = 5), midfield (n = 8) and forwards (n = 3). The highest body mass was found with the goalkeepers (74.4 ± 1.6 kg) followed by the defenders (61.0 ± 5.6 kg), midfield (64.6 ± 9.7 kg) and forwards (60.4 ± 5.2 kg). This trend was mirrored by the mean stature of each position collectively, with the forwards being the smallest group, followed by midfield, defenders and goalkeepers (Appendix X).

The sum of eight skinfold measurement mean ± standard deviation (mean ± S.D) for the squad, including outfield players and goalkeepers, was 109.4 ± 35.4 mm. These measures followed the same trend as the player mass results, with the forwards having the lowest sum of eight skinfold measures (104.3 ± 7.0 mm), followed by midfield (109.4 ± 35.4 mm) and defenders (117.8 ± 38.5 mm), who both demonstrated much larger variation. The goalkeepers had the highest sum of eight skinfold measures of the squad (135.5 ± 14.5 mm).

3.3.2 Repeat Sprint Ability

The repeat sprint ability assessment was conducted with a total of sixteen participants, however full data sets were complete with thirteen participants due to two timing gate errors and one withdrawal through injury.

The mean ± standard deviation results for total squad sprint times were 7.66 ± 0.44 secs and 33.79 ± 1.95 secs, for seven repeated efforts at five and thirty metres, respectively. The defenders overall had the quickest time for the five metre repeated sprints (7.46 ± 0.23 secs), with the forwards having the slowest total repeated time (7.82 secs); however this result was for just one forward player (n = 1). The thirty metre total sprint times were relatively homogeneous between outfield players (forward; 32.60 secs, defenders; 33.38 ± 0.75 secs, midfield, 33.64 ± 1.80 secs). The goalkeepers conversely were 6% slower than the mean outfield player scores (35.35 vs. 33.21 secs). The single sprint and total sprint scores for 30m underwent subsequent analysis to gauge the ‘fatigue index’, also known as percentage decrement score, following equation 3.0 (Glaister et al, 2008). The total squad and position specific scores are referenced within Table 3.1, where the midfield player's performance was considerably superior to the other player positions (a lower score represents greater consistency and ability to maintain repeated sprint performance without decrement; a higher score demonstrating increased influence of fatigue).

Table 3.1 A table indicating repeat sprint ability fatigue index scores

	Subjects	Fatigue Index (equation 3.0)	Fastest 30m (x7) (secs)	Total 30m (secs)
Total Squad	n = 13	11.23 ± 9.97	32.45 ± 2.56	33.79 ± 1.95
Goalkeepers	n = 2	7.25 ± 1.35	32.97 ± 0.77	35.35 ± 0.38
Defenders	n = 3	12.28 ± 8.92	31.61 ± 0.81	33.38 ± 0.75
Midfield	n = 7	3.54 ± 2.28	32.55 ± 2.45	33.64 ± 1.80
Forwards	n = 1	6.82	30.52	32.60

In terms of single sprint performance, the forwards had the fastest 5m sprint times, followed by midfield, defenders and goalkeepers (0.94 ± 0.00; 1.04 ± 0.07; 1.05 ± 0.03 and 1.08 ± 0.01 secs). The forwards were also quickest over thirty metres, but the trend was not continued over the other positions, with the defenders, goalkeepers and midfield results following (Appendix VI; Appendix XIX). Correlation values observed with repeat sprint ability scores and match-based analyses can be found within appendix XII and section 3.3.3 (match demands).

3.3.3 Match Demands

Match analysis data was collected from twelve outfield players over two matches using GPS devices (8 players remained consistent, with rotation of 2 players starting each game) and 11 outfield players (plus 4 substitute players) were monitored over a further three fixtures using the team heart rate monitoring system.

The total distance covered during the matches by all positions combined was 8273 ± 1608 m. Match analysis data from goalkeepers was not captured. The forward players covered the greatest distance, followed by the defensive players and midfield (appendix XVI). The total distance covered per minute by all players was 113.0 ± 11.5 m·min. In terms of high intensity distance covered, the total and breakdown is recorded on Table 3.2, where players averaged 289 ± 75m throughout the fixtures. The midfield players demonstrated the greatest ability to repeat high intensity distance, with 6.9% and 13.4% greater metres per minute distance covered than forwards and defenders, respectively (19.14 vs. 17.88 and 16.58 m·min). Additionally, total high intensity entries per minute (speeds ≥ 4.1 $m \cdot s^{-1}$) correlated significantly with both mean 30m repeated sprints (figure 3.2) and total thirty metre sprint times ($r = -0.77$, $R^2 = 0.52$; $p < 0.01$).

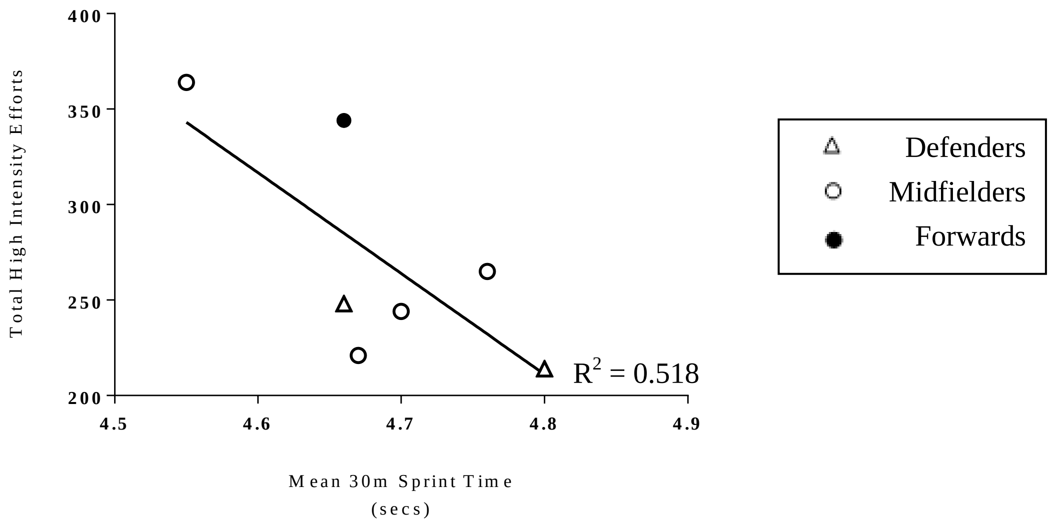

Figure 3.2 A scatterplot demonstrating mean 30m sprint times (secs) and total high intensity match day efforts achieved (n=7)

Table 3.2 A table demonstrating mean ± S.D high intensity match data (n = 12)

		Match Speed Distances				High Intensity Distance	
	Subjects	Speed Zone 5 (m)	Speed Zone 5* (Entries.min)	Speed Zone 6** (m)	Speed Zone 6 (Entries.min)	Total High Intensity (m)	Total High Intensity (Entries.min)
Total Squad	n = 12	210 ± 74.0	2.85 ± 1.04	67.5 ± 19.5	0.75 ± 0.24	289 ± 75.0	3.70 ± 1.38
Defenders	n = 3	219 ± 51.5	2.35 ± 0.54	62.5 ± 15.5	0.83 ± 0.32	281 ± 67.0	3.02 ± 0.70
Midfield	n = 7	220 ± 36.5	3.88 ± 1.16	70.0 ± 14.0	1.22 ± 0.19	257 ± 35.8	4.08 ± 1.01
Forwards	n = 2	253 ± 6.0	2.89 ± 0.23	80.5 ± 5.5	0.91 ± 0.11	333 ± 11.0	3.79 ± 0.33

* Speed Zone 5 = 4.1 – 5.0 $m \cdot s^{-1}$ ** Speed Zone 6 = ≥ 5.1 $m \cdot s^{-1}$

3.4 Discussion

3.4.1 Anthropometric Findings and Discussion

The body composition measurements attained and presented within the current study are unique within the literature, due to being the only study to summarise eight skinfold measurement sites with elite female soccer players. This may be an important factor due to the elite female soccer studies to date that analyse skin fold measures have done so over four and six sites (Davis and Brewer, 2002; Mujika et al, 2009), where the iliac crest is one of the measures to be excluded, which is also the third largest measure observed within the present study and could differ greatly between men and women. The subsequent predictive equations could also therefore provide skewed or underestimated percentage values. Essentially, it is feasible that previously recorded and documented body composition data with female players has not provided us with suitable or reliable comparisons. This is an important factor when gauging anthropometric development over time, but also in terms of the practical impact of how practitioners base their expectations of players they are working with.

The closest comparative study within elite female soccer is by Mujika and colleagues (2009), where sum of six skinfold measurements were taken from Spanish Super Liga players. After the present result findings had been adjusted (reduced to a total sum of six skinfold measure and goalkeeper values excluded), the FA WSL players had an eight per cent higher total body fat value than the elite female Spanish players observed (80.9 mm vs. 74.4mm). This equated to a body fat percentage of 16.1% and 15.6%, for the English and Spanish players respectively, using Yuhasz (1966) conversion equation. One reasonable explanation for this slight disparity could be that the measures observed within the

Super Liga were taken mid-season, with no specific date provided, whereas the FA WSL measures were taken prior to the start of pre-season.

The converted total body fat estimate of the full squad, including goalkeeper results, was 16.4% (equation; Yuhasz, 1966). In addition to the Spanish Super Liga players (Mujika et al, 2009), the body composition results were similar to elite Danish domestic league players (Krustrup et al, 2005) with 14.6%. This is contrasting to earlier studies where body fat percentage results from International players in excess of twenty per cent were commonplace (Colquhoun and Chad, 1986; Davis and Brewer, 1992; Withers et al, 1987).

Only one other study within the literature appears to also provide a breakdown of position specific anthropometric measurements, including body fat results, although this paper was focused toward physiological demands and analysis of match play and failed to provide the method of assessment for body composition (Krustrup et al, 2005). They also didn’t include goalkeeper data within this research, where they were found to have 19.5% body fat in the current study, however the forwards (16.1 vs. 15.8%), defenders (15.4 vs. 15.1%) and midfield (12.5 vs. 12.2%) were found to be remarkably homogeneous between the Danish first division and the FA Women’s Super League elite female soccer players, respectively. This is potentially unsurprising given semi-professional Danish teams are represented similarly to English semi-professional teams in the UEFA Women’s Champions League, and include equally similar number of International players in the top sides, where England are currently placed eighth and Denmark fifteenth in the FIFA Coca-Cola Women’s Ranking. The current research included eight Senior England players, one Senior USA player, one Icelandic International player, one Senior Swedish International player, one Senior German International player and one Under-23 USA representative.

The sum of eight skin fold measurement totals within the present research demonstrated a significant relationship with repeat sprint ability, and more specifically to mean thirty metre ($P \leq 0.05$; figure 3.1) and total thirty metre sprints ($P \leq 0.05$; appendix XIII). This is a finding not reported within female soccer literature to date, and although both anthropometric and repeat sprint ability have been measured within male soccer (da Silva et al, 2010; Chaouachi et ffial, 2010; Meckel et al, 2009), no associations have also been conveyed between lower body fat measures and RSA. The only presumed relationship, to this author's knowledge, has been by Reilly et al (2000) who concluded, when assessing young elite and sub-elite players, that elite players were significantly leaner, possessed more aerobic power and were more tolerant of fatigue. This being a unique finding is surprising given it being well-known that a higher body fat percentage is related to decrements in athletic performance, particularly in activities where bodyweight must move horizontally or vertically (Hergenroeder and Klish, 1990).

3.4.2 Repeat Sprint Ability Findings and Discussion

Owing to the large number of RSA protocols in existence within the research (Balsom, 1990; Boone et al., 2012; Chamari et al, 2004; Glaister et al, 2008; Malomski, 1993) discussions surrounding the present study is difficult given the different physiological implications from the variety of RSA protocols (Meckel et al, 2009). For example, even when taking similar intermittent sports such as field-hockey (Bishop et al, 2003; Bishop and Edge, 2006) into consideration, comparisons are futile due to the varying distances, number of sprints and recovery times administered for each RSA protocol. One similar study, however, included a set of three thirty metre sprint assessments with a twenty five second recovery in-between (rather than seven thirty metre sprints with twenty seconds to complete the sprint and recover, as conducted in the present study) where Krustrup and colleagues (2010) were assessing sprint performance before and after an elite competitive female soccer game. Despite the shorter recovery time and greater number of sprints completed, players in the current study were marginally quicker when sprint times were averaged (4.86 ± 0.06 vs. 4.83 ± 0.28 secs). The greater variability within the present research was assumed to be owing to inclusion of goalkeeper results, which demonstrated the slowest thirty metre times and were not included in the research by Krustrup et al (2010), although exclusion of these players provided only marginally increased standardisation

(4.80 ± 0.25 secs). Additionally, the Danish players monitored had a higher body fat percentage in relation to the FA WSL players (18.5% and 16.4%, respectively), which may have an impact on RSA (section 3.3.1).

In terms of isolated sprint times, many of the assessments conducted within elite female soccer players are over distances other than thirty metres (20m, Andersson et al, 2008; 20m, Cox et al, 2002; 20m and 40m, Haugen et al, 2012; 36.6m Vescovi et al, 2011), making player performance comparison with the current study impossible. However, relative values are possible from young female handball players (14 ± 1.06 yrs) where the fastest thirty metre sprint time recorded was 4.63 secs; quicker than the elite soccer players in the current study. This result may not be a true reflection of capabilities, due to the female soccer players understanding that they are required to complete seven maximal sprints (therefore consciously or unconsciously, it’s possible a pacing strategy was employed, as predicted by Svensson and Drust (2005)). Although repeated bouts of less than eight repetitions has been found to decrease the likelihood of a pacing strategy being employed (Fitzsimmons et al, 1993), a single effort first and foremost should ideally be completed ahead of the RSA assessment to determine the maximal velocity first (Oliver, 2009). A further judgement could be made alongside female competitive sprinters, however the thirty metre sprint was combined within a hundred metre and three hundred metre assessment and therefore results are not transferable (Hennessy and Kilty, 2001).

In relation to the five metre sprint element of the testing performed, despite this not relating significantly to either anthropometric or match-play data observed, this still provides a valuable indicator of acceleration capabilities. The quickest five meter time recorded by the players within the present research was 1.02 ± 0.08 secs, which was twelve per cent faster than results reported with elite under fifteen age group female players (1.16 ± 0.07 secs) (Taylor et al, 2012). Although this does not particularly provide us with data of significance between groups, especially given anaerobic power and capacity is less developed in children (Bar-Or and Unnithan, 1994; Borms, 1986), it is of interest to comprehend the potential development of this fitness component over time. This is also pertinent due to the youth players being 'English FA Girls Centre of Excellence' players and eight of the thirteen players measured in the present study being England International players. This study by Taylor and colleagues (2012) also provides longitudinal measurements pre-, mid- and post-season allowing fluctuations within performance indicators to be monitored over time.

The findings within this study, regarding the assessment and translation of field-based RSA results, provide total 30m time (table 3.1) (the sum of all seven sprint efforts combined) and mean 30m time (figure 3.2); suggested as the most appropriate measures for reliable tracking of meaningful change over time (Oliver, 2009). However, fatigue index scores have also been calculated using the primary equation suggested by Glaister et al (2008) and reported (table 3.1, section 3.3.2). This potentially causes confusion relative to which measure the current thesis study gleans to be the most worthwhile whilst assessing and providing feedback for players and coaches on repeated occassions regarding RSA performance. A rigorous assessment of the literature on this subject in particular and use of one of the methods within the results section may have provided greater clarity.

3.4.3 Match Demands Findings and Discussion

The total distance covered during the matches within the current study were lower than described previously with elite female soccer players domestically, such as Danish First Division (10.3 km; Krustrup et al, 2005), US professional (10.0 km; Vescovi, 2012) as well as Internationally, with Australian (9.1 km; Hewitt et al, 2004) and Nordic players (10.0 km; Anderrson et al, 2007), for example. This could be the influence of playing lesser opponents during the FA WSL pre-season, where the work-rate may be decreased as a consequence (Folgado et al, 2014), which is possible given these games were won comfortably against clubs in the league below (3-0 against Manchester City Ladies and 4-1 against Leeds United Ladies). In terms of player positions, the current study observed that the forwards covered the greatest distance, followed by defensive positions and midfield (Appendix XVI), which was in contrast to previous elite female soccer, where the forwards displayed the lowest total distance and midfielders the highest (Gabbett and Mulvey, 2008; Hewitt et al, 2004) and elite male findings (Bradley et al, 2009; Reilly and Thomas, 1976). Anecdotally, it's possible this discrepancy could occur through different tactics employed, or alternatively incoherent tactics and unclear roles within those, given the squad was newly formed and these games represented the first played as a group, as well as a desire for each player to prove themselves in a new set-up; both scenarios potentially resulting in unexpected positional behaviour. Secondly, it's worth noting that this study is insufficiently powered for conclusions to suitably be made regarding match analysis, both from a player perspective (n=12) and number of matches analysed (just 2 out of 5 fixtures monitored using GPS analysis). Examples such as studies from Malone and colleagues (2015), who measured 111 (6 - 189) EPL training sessions using GPS devices, and Bush et al (2015) who captured 14,700 EPL match observations, demonstrate how larger sets of data can provide greater clarity from an applied perspective with consistent patterns emerging.

The insufficient number of games analysed within the present research may impact most significantly when high intensity activities observed, due to the large inter-game variability noted by Gregson and colleagues (2010); albeit in an elite male population. Comparisons of high intensity distance, as previously alluded to, are often difficult to distinguish between studies. For instance, a similar cohort of scholarship and International players were monitored by Gabbett and Mulvey (2008) during training sessions using a video camera in a grid of a known dimension. They assessed steps per second and meters per step for walking, jogging, striding and sprinting, which were then applied when filming competitive matches. As this method provides no absolute speed values, there's no mechanism for evaluation with other studies, including this study conducted. However, this process does take individual player speeds into consideration which research with fixed speed values doesn't account for. For example, the locomotor activities measured within a handful of elite female soccer studies stipulate speeds $\geq$ 15 $km \cdot hr^{-1}$ considered high intensity (Andersson et al, 2008; Krustrup et al, 2005; Mohr et al, 2008); also using a video camera with subsequent computerised coding. These examples, as well as the present study, make the presumption that all players elicit the same striding and sprinting speeds throughout the game, or don't account for that fact that player movement speeds are very different (appendix XII).

The high intensity threshold for the current research undertaken was ≥ 4.1 $m \cdot s^{-1}$ (speed zones 5 and 6 combined; appendix XVI), which translates to 14.76 $km \cdot hr^{-1}$; similar to the ≥ 15 $km \cdot hr^{-1}$ described in the previous studies discussed (Andersson et al, 2008; Krustrup et al, 2005; Mohr et al, 2008). The high intensity match distance covered during the present research was 1.42 km, which is further than players monitored in the top Danish soccer league (1.13 km; Krustrup et al, 2005), but not as high as US professional soccer players, who all represented their respective countries, found to cover 1.68 km (Mohr et al, 2008). During this latter study, these top-class players were compared with domestic level players, who had not represented their countries internationally, and found to complete twenty eight per cent greater distances at higher intensity than their counterparts (Mohr et al, 2008). This may be an adaptive response to the increased intensity during international vs. domestic fixtures, or even a selection criterion for this level of international performance (Anderson et al, 2007; Gabbett and Mulvey, 2008). In terms of position specific performance, the midfield players demonstrated the greatest ability to repeat high intensity efforts, with 6.9% and 13.4% greater distance covered per minute of the fixtures than the forwards and defenders, respectively (19.14 vs. 17.88 and 16.58 m·min). This was also found when Gabbett and Mulvey (2008) reported the work to rest ratios of elite female soccer players during international competition, where the midfield players rested less during these games with a 1:10 work: rest ratio, vs. 1:13 for the forwards and 1:15 defenders.

The current study found a significant correlation between mean and total thirty metre RSA assessment time and total high intensity entries per minute (e.g. the number of occasion players reached and surpassed speeds of 4.1 $m \cdot s^{-1}$) during the fixtures analysed. Although this relationship appears intuitive, the direct translation is not always apparent or comprehensively researched, particularly in relation to female soccer. Aerobic capacity is the fitness parameter that has been most positively identified in relation to high intensity capability, using the YoYo Intermittent Recovery Test as an assessment tool (Krustrup et al, 2003; Krustrup et al, 2005; Mohr et al, 2003). Despite this assessment involving repeated efforts and having a high anaerobic contribution (Bangsbo et al, 2008), the intensity is too low for this to suitably reflect repeated sprint ability, however is has been used as a successful indicator for physical performance during competitive matches (Krustrup et al, 2005) and differentiating between level of female soccer performance too (Bradley et al, 2014). The only demonstration, as far as this author is aware, of the soccer transition of field based RSA assessment and match performance was by Rampinini and colleagues (2007) in elite male players, who found a significant relationship between $\geq$19.8 km·hr^{-1} speed distance (very high intensity running and sprinting) and RSA mean time. These findings are similar to those of the current study, within elite female soccer players (section 3.3.2 and 3.3.3).

Despite the notion that field and laboratory testing should never be used to predict actual on-field performance (Svensson and Drust, 2005), it is clearly advantageous to recognise the assessments practitioners use to evaluate progression in isolated parameters also suitably reflect aspects of the game they are training toward. However, although evidence herein (section 3.3; Rampinini et al, 2007) demonstrate that field-based performances reflect match-based performances, this isn’t necessarily due to the RSA assessment emulating game demands. Gabbett et al (2013) reported repeat sprint activity (defined as a minimum of three sprints with $\leq$ 20 seconds between sprints) of 10 national and 5 international competitive matches and found some players performed no repeated bouts and some players performed up to twenty-three. The two most striking findings however indicate that the most common sprint bouts consisted of just two efforts with average sprint duration of 2.17 ± 0.13 secs. This study by Gabbett and colleagues (2013) demonstrates principally that accepted descriptions and assessments of RSA are not representative in relation to elite female soccer.

3.4.4 Future Anthropometric Study Recommendations

The following topics of further research would be beneficial to enhance knowledge and application of body composition variation and ideals within female elite soccer;

- Research dedicated to anthropometric measurement toward accurate body fat specific to female soccer players, similar to work of Reilly et al (2009) within elite male soccer, would be worthwhile. Despite the sum of eight skinfold measurements advocated by ISAK (Hume and Marfell-Jones, 2008) being relatively all-encompassing, this is time consuming and often impractical within applied settings. Therefore, a prediction equation which provides an acceptable level of accuracy, whilst reducing the number of sites required or time involved (as well as ideally providing an estimate on muscle mass with the inclusion of limb girth measurements) would be of benefit within elite female soccer.
- A greater increase in the publication of body fat measurements within elite female soccer would provide valuable comparative figures. Currently much of the literature provides simply body mass and height (Haugen et al, 2012; Hewitt et al, 2007; Vescovi, 2006) or was published prior to semi-professional league set-ups (Colquhoun and Chad, 1986; Davis and Brewer, 1992; Withers et al, 1987) and therefore measurements stated do not necessary represent modern player values.
- In addition to the above, research focusing on longitudinal fluctuations of body composition and body fat of female players within the top soccer leagues would help to provide guidance around ideal markers prior to pre-season, end of pre-season, maintenance values throughout the season as well as end of the season. To date, this has only been looked at on two occasions over a twelve month period (Davis et al, 1992). This would be particularly interesting and progressive alongside related fitness determinants, similar to the work of Caldwall and Peters (2009) or Clark and colleagues (2008) in elite male soccer.

- A greater predominance of position specific body composition guidelines within female soccer would be of use, to add to the single study in existence (Krustrup et al, 2005). This would help to shape understanding and provide guidance around expectations of body fat for various positions, with a view toward optimising performance, rather than stipulating that all player positions need to meet a similar threshold.
- Presently no studies have provided information on ethnicity within female soccer, or an indication of how ethnicity may alter the body composition results observed. Although this has been researched in the general population (Ellis et al, 1997) it is likely these results do not transfer through to athletic or soccer specific groups.

3.4.5 Future Repeat Sprint Ability Study Recommendations

The following points have been highlighted, from examination of current literature and throughout the present research undertaken, as potential areas of progression of RSA research within female soccer;

- There are a large number of studies in existence which provide a variety of options for repeat sprint ability assessment (Balsom, 1990; Boone et al., 2012; Chamari et al, 2004; Malomski, 1993; for example), which illicit a different physiological response (Meckel et al, 2009). Some papers have consolidated these, as well as the subsequent equations used to evaluate a 'fatigue index' score (Glaiser et al, 2009), however greater consistency is required within the literature regarding the testing performed. It is understandable that the RSA testing is required to replicate the intensity, distances and rest periods that players may encounter during competitive fixtures (and most challenging scenario encountered); potentially therefore, one RSA assessment should be specific to each sport and even level of competition.
- The RSA protocols published to date either exclude goalkeepers from the assessments performed and offer no alternative, or incorporate goalkeepers within the assessment, which often includes distances and work-intensities that are not specific to their positional requirements (including the current

study). It would be hugely beneficial therefore for knowledge surrounding goalkeeper activity profiles to be accumulated and specific RSA protocols developed.

- In relation to position specific assessments, and in addition to the above point, a specific RSA protocol could also be developed toward disparate outfield positions. For instance, from data derived from Gabbett and Mulvey (2008) with International female soccer players demonstrates that firstly sprint distance covered is different between positions (1184 ± 146; 981 ± 317; 820 ± 327 m, for attackers, midfield and defenders, respectively), as well as the maximal sprinting duration (2.7 ± 1.2; 3.0 ± 0.3; 2.9 ± 0.8 secs, for attackers, midfield and defenders, respectively) and therefore evidently the ensuing recovery time appears to be very different between attackers and midfield (6.7 ± 3.8 and 6.6 ± 4.0 secs) than defenders (4.3 ± 3.7 secs). Therefore, an RSA protocol which is explicitly designed toward female soccer, and secondly a set of protocols which demonstrate greater playing position specificity, would be possible to develop and potentially be of benefit to more realistically represent the demands of the game.
- A greater understanding of the contributing factors impacting RSA would be of use, as these results are generally reported in isolation, rather than in relation to aerobic capabilities, anthropometric measurements, strength / power assessments and most pertinently relative to actual match performance (particularly games played at a very high intensity).

3.4.6 Future Match Demands Study Recommendations

The following are areas of suggested consideration for future research focusing on match analysis within female soccer, either identified within existing literature or present investigations conducted;

- The current publications analysing competitive female soccer fixtures have only provided data within three distinct positions (defenders, midfield, forwards) (Gabbett and Mulvey, 2008; Hewitt et al, 2004; Mohr et al, 2008; Vescovi, 2012), whereas recent examples exist within elite male soccer, where these have been further split into centre-backs, full-backs, central-midfielders and wide-midfielders (Bradley et al, 2009; Di Salvo et al, 2009; Di Salvo et al, 2010). This may be due to comparatively lower subject numbers within female soccer, as elite male soccer data have had access to analyse over five hundred players (Di Salvo et al, 2009) and 28 games (Bradley et al, 2009) for example, using semi-automated multi-camera image recognition systems (such as ProZone®, mentioned in section 3.1.3). Anecdotally, this technology is used occasionally within female soccer when playing in stadiums that are already fitted with a camera system; however, additional funding is also required for the analysis and subsequent feedback, which often isn't possible for domestic clubs or international teams. However, a clearer intra-positional breakdown would still be of benefit within female soccer, given the clear physiological demand dissimilarity between full-backs and centre-backs, as well as wide-midfielders and central-midfielders. Furthermore, the ability to leverage more advanced technologies, that can capture competitive match outputs in a non-invasive or disruptive fashion, would be hugely advantageous to progress application of sports science within female soccer.

– In addition to the unavailability of in-game multi-camera image recognition systems for applied feedback and research, GPS devices are also rarely used within female soccer, with the exception of international squads. Barbero-Álvarez et al (2008) used GPS to analyse young female soccer players, with at least three years playing experience, and Hewitt and colleagues (2007) used GPS to determine work-rate of Australian international players during a tournament. However, these are rare examples within the literature, as well as only examining one and four matches, respectively (Barbero-Álvarez et al, 2008; Hewitt et al, 2007). This is similar to the present study, where five fixtures were targeted, but only two analysed games were achieved with GPS. These low numbers of fixtures analysed make it difficult and potentially imprudent for accurate work rate assumptions to be established, due to a number of factors, including the high match variability, variety of opponents, environmental factors and even different starting and substituted players. This practice of low fixture reporting is not only reserved for matches using GPS, this is also commonplace where video cameras are the method of analysis for female soccer (Andersson et al, 2007; Gabbett and Mulvey, 2008; Mohr et al, 2008). Therefore, greater numbers of matches monitored and analysed on a continuous basis would be valuable, allowing a ‘position-stand’ to be established, recognised and targeted toward, not only for the female game, but within male soccer too.

3.5 Conclusion

The current study aimed to investigate the anthropometric and anaerobic characteristics of elite female soccer players, at the start of pre-season, prior to the FA Women's Super League campaign. The anaerobic facets of performance were split into measurement of field-based RSA (7 x 30m in 20 sec intervals) and high intensity match day efforts performed (categorised as speeds of 4.1 m•s and over).

The results demonstrate that players' body fat, determined by sum of eight skinfolds, has a significant relationship with RSA. This provides applied practitioners with further insight toward justification for body composition adaptations and underpinning knowledge from which individualised anthropometric guidelines might be built and adapted. Furthermore, RSA was significantly correlated to the number of match-based high intensity efforts performed. This provides direct rationale for use of this assessment to successfully determine players' game specific anaerobic capacity, alongside other established test procedures. This finding also highlights the importance of the ability to perform maximal sprints repeatedly within elite female soccer; a concept well established and recognised within professional male soccer, but relatively new to the female literature.

CHAPTER IV GENERAL CONCLUSION

This Masters (research) thesis aimed to explore two areas of soccer science, yet to be investigated with elite male and female players. These studies were conducted with the overarching objective of providing unpinning scientific evidence in order to better inform applied practice.

The first study (Chapter II) established that within professional male soccer players, the lowest maximal aerobic capacity values are observed at EOS, compared with the subsequent PTP and PPS measurements. These results suggest that aerobic capacity declines toward the end of an EPL season. The lowest body fat measurements were also recorded at EOS. The second study (Chapter III) also investigated anthropometric values in conjunction with physical performance measures, and found that in semi-professional female players, body fat is significantly related to RSA. In addition, field-based RSA results were correlated to match-based high intensity efforts, demonstrating the test's applicability within elite female soccer.

Two pertinent points are illustrated throughout this thesis research, which present findings of benefit to applied practitioners. In elite female soccer, the RSA field-based assessment utilised within this research (7 x 30m sprints with 20 second intervals) proved a valid tool to differentiate players' on pitch repeated high intensity capabilities ($\geq$ 4.1 m·s). Players' body fat was also found to correlate positively to RSA performance. In elite male soccer, this study found laboratory-based assessments of metabolic function provide a viable method to distinguish aerobic capacity change over an EPL season. As this research proposes possible aerobic capacity decrease toward the end of the season, where peaks in performance are arguably most important, further research into inter-season measurements would be valuable, as well as investigation and implementation of efficient aerobic maintenance methods. The lowest body fat measurements observed EOS signifies that energy imbalance could also be a performance limiting factor.

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CHAPTER VI APPENDICES

Appendix I. Ethics scrutiny application

UNIVERSITY OF BEDFORDSHIRE

Research Ethics Scrutiny (Annex to RS1 form)

SECTION A To be completed by the candidate

Registration No: *1231122*

Candidate: *Miss Tessa Morris*

Degree of: *Master of Science by Research*

Research Institute: *Institute for Sport and Physical Activity Research (ISPAR)*

Research Topic: *The specific fitness requirements and match demands of elite male and female soccer.*

External Funding:

The candidate is required to summarise in the box below the ethical issues involved in the research proposal and how they will be addressed. In any proposal involving human participants the following should be provided:

- clear explanation of how informed consent will be obtained,
- how will confidentiality and anonymity be observed,
- how will the nature of the research, its purpose and the means of dissemination of the outcomes be communicated to participants,
- how personal data will be stored and secured
- if participants are being placed under any form of stress (physical or mental) identify what steps are being taken to minimise risk

If protocols are being used that have already received University Research Ethics Committee (UREC) ethical approval then please specify. Roles of any collaborating institutions should be clearly identified. Reference should be made to the appropriate professional body code of practice.

<u>Informed Consent</u>

The subjects participating in this study will each receive and sign a statement of informed consent, which clearly details the protocols and assessments to be undertaken. Additionally, this document will include a confidentially agreement, stating that no names will be associated with the data and personal data will be treated in confidence. In-line with this written description of procedures, a verbal explanation (by student, Tess Morris) will also be given to confirm details have been fully understood. The participant will then sign the appropriate section of the document, as well as a witness signature.

<u>Confidentiality and Anonymity</u>

Prior to any commencement of testing protocols, each participant will be given a code (e.g. 1a) from which they can be identified from a central database. This will be under the responsibility of the Medical staff at the respective football clubs where testing is taking place (cont.)

This coding system allows the players and staff to complete datasheets, which include sensitive information, without compromising the confidentiality of the athlete involved. One copy of the coded database will then be saved under password for my research purposes only.

Communication to Participants

A results report (using coded player data) will be given to the Medical Team at the respective football clubs, including insight into the data and offering solutions and explanations, which may help inform applied practice. The results and explanation of these to each participant will be the responsibility of the Medical Team within each football club environment.

Storage and Security of Personal Data

The personal data collated during testing will be stored on one central computer, within the medical department at each football club training ground. These computers are password protected, which only the Head of Sports Science for each facility will have access to. This file will also have a 'coding system' (as previously described), whereby the data I receive will not have any names of the participants. This will also be password protected and efforts made towards its security and safe-keeping. All collection and storage of data will be within The Data Protection Act (1998) guidelines.

Stress Management

Physical Stress identified:

- Laboratory-based graded aerobic assessment, designed to take participants to maximal capacity.
- Field-based intermittent assessment, designed to take participants to maximal capacity.

The statement of informed consent and prior communication to all participants will reiterate that they hold the right to withdraw at any time, with no obligation to provide reasons for the decision. Secondly, that the opportunity to discuss any concerns and for further questions will be provided.

Answer the following question by deleting as appropriate:

1. Does the study involve vulnerable participants or those unable to give informed consent (e.g. children, people with learning disabilities, your own students)?

   ~~Yes~~ **No**

   If **YES**: Have/will Researchers be CRB checked?
   Yes **No**

2. Will the study require permission of a gatekeeper for access to participants (e.g. schools, self-help groups, residential homes)?

   ~~Yes~~ **No**

3. Will it be necessary for participants to be involved without consent (e.g. covert observation in non-public places)?

   ~~Yes~~ **No**

4. Will the study involve sensitive topics (e.g. sexual activity, substance abuse)?
   ~~Yes~~
   No

5. Will blood or tissue samples be taken from participants?

   ~~Yes~~ **No**

6. Will the research involve intrusive interventions (e.g. drugs, hypnosis, physical exercise)? **Yes**
   ~~No~~

7. Will financial or other inducements be offered to participants (except reasonable expenses)? **~~Yes~~** **No**

8. Will the research investigate any aspect of illegal activity?
   ~~Yes~~ **No**

9. Will participants be stressed beyond what is normal for them?
   ~~Yes~~ **No**

10. Will the study involve participants from the NHS (e.g. patients) or participants who fall under the requirements of the Mental Capacity Act 2005?

    ~~Yes*~~ **No**

If you have answered yes to any of the above questions or if you consider that there are other significant ethical issues then details should be included in your summary above. If you have answered yes to Question 1 then a clear justification for the importance of the research must be provided.

Checklist of documents which should be included:

Project proposal (with details of methodology) & source of funding	✓
Documentation seeking informed consent (if appropriate)	
Information sheet for participants (if appropriate)	

Questionnaire (if appropriate)	

(Tick as appropriate)

Signature of Applicant: Date: *10th of April 2013*

Signature of Director of Studies: Date: *10th of April 2013*

This form together with a copy of the research proposal should be submitted to the Research Institute Director for consideration by the Research Institute Ethics Committee/Panel

Note you cannot commence collection of research data until this form has been approved

SECTION B To be completed by the Research Institute Ethics Committee:

Comments:

Approved

Signature Chair of Research Institute Ethics Committee: ***See Appendix II***

Date:

This form should then be filed with the RS1 form

If in the judgement of the committee there are significant ethical issues for which there is not agreed practice then further ethical consideration is required before approval can be given and the proposal with the committees comments should be forwarded to the secretary of the UREC for consideration.

Appendix II. Ethics scrutiny approval confirmation

University of Bedfordshire

Research Graduate School
University Square Luton
Bedfordshire LU1 3JU
United Kingdom
research@beds.ac.uk
www.beds.ac.uk

17 September 2013

Ethical scrutiny confirmation

Proposer:	Tessa Morris
Proposal short title:	The specific fitness requirements and match demands of elite male and female soccer

Dear Proposer

Your proposal has now received ethical scrutiny from the Institute for Sport and Physical Activity Research Ethics panel.

I can confirm that this has now been approved, please find below your approval number:

Approval number: **2013ASEP023**

Please note that if it becomes necessary to make any substantive change to the research design, the sampling approach or the data collection methods a further application will be required

You are now clear to proceed with data collection for this project.

Thank you very much for your patience in this matter

Regards

David Kirk

Prof David Kirk (ISPAR Director)

Appendix III. Skin Fold Procedures

International Society for the Advancements of Kinanthropometry (ISAK)

Measuring Technique

- Check skinfold caliper is measuring accurately and make sure that the needle is on zero.
- Locate skinfold site using the correct anatomical landmarks. Marking the skin for all skinfold landmarks minimises location errors for repeat measurements.
- The skinfold is picked up at the marked line. It should be grasped and lifted (raised) so that a double fold of skin plus the underlying subcutaneous adipose tissue is held between the thumb and index finger of the left hand, with the back of the hand facing the measurer. Care must be taken not to incorporate underlying muscle tissue in the grasp. In order to eliminate muscle, the finger and thumb roll the fold slightly thereby also ensuring that there is a sufficiently large grasp of the fold.
- The nearest edge of the contact faces of the caliper are applied 1 cm away from the edge of the thumb and finger. As a guide, the caliper should be placed at a depth of approximately mid-fingernail.
- The caliper is held at 90° to the surface of the skinfold site at all times.
- Measurement is recorded two seconds after the full pressure of the caliper is applied and skinfold sites should be measured in succession to avoid experimenter bias. That is, a complete data set is obtained before repeating the measurements.
- Skinfold measurements should not be taken after training or competition, sauna, swimming or showering, since exercise, warm water and heat produce hyperaemia (increased blood flow) in the skin with a concomitant increase in skinfold thickness.

Measuring Site Locations

1. Triceps

Subject assumes relaxed standing position with arms relaxed by their sides.
The right arm should be relaxed with the shoulder joint slightly externally rotated and elbow extended by the side of the body.

Method: The skinfold is taken parallel to the long axis of the arm.

2. Subscapular

Subject assumes relaxed standing position with arms relaxed by their sides.

Method: The line of the skinfold is determined by the natural fold lines of the skin.

3. Biceps

Subject assumes relaxed standing position with arms relaxed by their sides.
The right arm should be relaxed with the shoulder joint slightly externally rotated and elbow extended by the side of the body.

Method: The skinfold is taken parallel to the long axis of the arm.

4. Iliac Crest

Subject assumes relaxed standing position with left arm relaxed by their side. The right arm should be either abducted or placed across the trunk.

Method: The line of the skinfold generally runs slightly downward posterior-anterior, as determined by the natural fold lines of the skin.

5. Supraspinale

Subject assumes relaxed standing position with arms relaxed by their sides.

Method: The fold runs medially downward at about a 45° angle as determined by the natural fold of the skin.

6. Abdominal

Subject assumes relaxed standing position with arms relaxed by their sides.

Method:This is a vertical fold. It is particularly important at this site that the measurer is sure the initial grasp is firm and broad since often the underlying musculature is poorly developed. This may result in an underestimation of the thickness of the subcutaneous layer of tissue. (Note: Do not place the fingers or caliper inside the navel.)

7. Front Thigh

The subject assumes a seated position at the front edge of the box with the torso erect and the arms hanging by the sides. The knee of the right leg is usually bent at a right angle. In some subjects, this skinfold may be easier to take with the knee extended.

Because of difficulties with this skinfold, three methods are recommended:

Method A

The measurer stands facing the right side of the subject on the lateral side of the thigh. The skinfold is raised at the marked site. The skinfold measurement is taken while the knee is bent. This is the standard and preferred method.

Method B

If the fold is difficult to raise the subject is asked to assist by lifting with both hands the underside of the thigh to relieve the tension of the skin.

Method C

For subjects with particularly tight skinfolds, the subject is asked to assist by lifting the underside of the thigh as in (b). The recorder (standing on the medial aspect of the subject’s thigh) assists by raising a fold with both hands at about 6 cm either side of the landmark. The measurer then raises the skinfold at the marked site).

If the skinfold is difficult to take with the knee flexed, ask the subject to extend the knee (Figure 44 D). Any of the three methods (A, B and C) may be used with the knee extended if necessary.

8. Medial Calf

The subject assumes a relaxed standing position with the arms hanging by the sides and the right foot placed on the box. The right knee is bent at about 90°.

Method: The subject's right foot is placed on a box with the calf relaxed. The fold is parallel to the long axis of the leg.

Appendix IV. Male soccer date of measurement and anthropometric P-values (n=28)

		May (EOS)	July (PPS)	August (EOP)
Body Mass (kg)	May	-	0.999	0.891
	July	0.999	-	0.893
	August	0.891	0.893	-
Sum of 8 Skin Fold Measures (mm)	May	-	0.197	0.497
	July	0.197	-	0.539
	August	0.497	0.539	-
Triceps Skin Fold Measure (mm)	May	-	0.265	0.429
	July	0.265	-	0.744
	August	0.429	0.744	-
Subscapular Skin Fold Measure (mm)	May	-	0.563	0.849
	July	0.563	-	0.698
	August	0.849	0.698	-
Biceps Skin Fold Measure (mm)	May	-	0.309	0.553
	July	0.309	-	0.669
	August	0.553	0.669	-
Iliac Crest Skin Fold Measure (mm)	May	-	0.298	0.760
	July	0.298	-	0.461
	August	0.760	0.461	-
Supraspinale Skin Fold Measure (mm)	May	-	0.140	0.749
	July	0.140	-	0.245
	August	0.749	0.245	-
Abdominal Skin Fold Measure (mm)	May	-	0.316	0.506
	July	0.316	-	0.735
	August	0.506	0.735	-
Front Thigh Skin Fold Measure (mm)	May	-	0.315	0.653
	July	0.315	-	0.579
	August	0.653	0.579	-
Medial Calf Skin Fold Measure (mm)	May	-	0.459	0.505
	July	0.459	-	0.940
	August	0.505	0.940	-
Mid-Thigh Girth (cm)	May	-	0.994	0.853
	July	0.994	-	0.846
	August	0.853	0.846	-
Max-Forearm Girth (cm)	May	-	0.947	0.828
	July	0.947	-	0.777
	August	0.828	0.777	-
Max-Calf Girth (cm)	May	-	0.720	0.617
	July	0.720	-	0.887
	August	0.617	0.887	-

Appendix V. **Anthropometric skinfold and girth measures from male soccer players; P-value correlations (n=43) (1)**

	Age (yrs)	Body Mass (kg)	Stature (cm)	Thigh Girth Mid (cm)	Forearm Girth Max (cm)	Calf Girth Max (cm)
Age (yrs)	-	0.001**	0.299	0.824	0.824	0.824
Body Mass (kg)	0.001	-	0.000**	0.000**	0.000**	0.000**
Stature (cm)	0.299	0.000**	-	0.999	0.350	0.091
Sum of 8 Skin Folds (mm)	0.202	0.020*	0.082	0.254	0.293	0.059
Triceps Sf (mm)	0.941	0.073	0.326	0.078	0.274	0.060
Subscapular Sf (mm)	0.067	0.001**	0.366	0.026*	0.063	0.009**
Biceps Sf (mm)	0.451	0.440	0.717	0.842	0.971	0.107
Iliac Crest Sf (mm)	0.078	0.019*	0.019*	0.394	0.605	0.098
Supraspinale Sf (mm)	0.335	0.027*	0.056	0.277	0.421	0.126
Abdominale Sf (mm)	0.035*	0.054	0.303	0.470	0.603	0.311
Front Thigh Sf (mm)	0.746	0.125	0.118	0.373	0.256	0.032*
Medial Calf Sf (mm)	0.302	0.411	0.024	0.929	0.274	0.491
Thigh Girth - Mid (cm)	0.022*	0.000**	0.999	-	0.000**	0.000**
Forearm Girth – Max (cm)	0.356	0.000**	0.350	0.000**	-	0.006**
Calf Girth – Max (cm)	0.028*	0.000**	0.091	0.000**	0.006**	-

* Indicates significance at $P \leq 0.05$ ** Indicates significance at $P \leq 0.01$

Table VI. **Anthropometric skin fold and girth measures from male soccer players; P-Value correlations (n=43)**

	Sum of 8 Skin Folds (mm)	Triceps Sf (mm)	Subscapular Sf (mm)	Biceps Sf (mm)	Iliac Crest Sf (mm)	Supraspinale Sf (mm)	Abdominale Sf (mm)	Front Thigh Sf (mm)	Medial Calf Sf (mm)
Age (yrs)	0.202	0.941	0.067	0.451	0.078	0.335	0.035*	0.746	0.302
Body Mass (kg)	0.020*	0.073	0.001	0.440	0.019*	0.027*	0.054	0.125	0.411
Stature (cm)	0.082	0.326	0.366	0.717	0.019*	0.056	0.303	0.118	0.024*
Sum of 8 Skin Folds (mm)	-	0.000**	0.000**	0.000**	0.000**	0.000**	0.000**	0.000**	0.000**
Triceps Sf (mm)	0.000**	-	0.000**	0.000**	0.000**	0.000**	0.000**	0.000**	0.000**
Subscapular Sf (mm)	0.000**	0.000**	-	0.000**	0.000**	0.000**	0.000**	0.002**	0.013*
Biceps Sf (mm)	0.000**	0.000**	0.000**	-	0.001**	0.005**	0.000**	0.003**	0.002**
Iliac Crest Sf (mm)	0.000**	0.000**	0.001**	0.000**	-	0.000**	0.000**	0.000**	0.000**
Supraspinale Sf (mm)	0.000**	0.000**	0.000**	0.005**	0.000**	-	0.000**	0.000**	0.000**
Abdominale Sf (mm)	0.000**	0.000**	0.000**	0.000**	0.000**	0.000**	-	0.000**	0.000**
Front Thigh Sf (mm)	0.000**	0.000**	0.002**	0.003**	0.000**	0.000**	0.000**	-	0.000**
Medial Calf Sf (mm)	0.000**	0.000**	0.013*	0.002**	0.000**	0.000**	0.000**	0.000**	-
Thigh Girth - Mid (cm)	0.254	0.078	0.026*	0.842	0.394	0.277	0.470	0.373	0.929
Forearm Girth – Max (cm)	0.293	0.274	0.063	0.971	0.605	0.421	0.603	0.256	0.274
Calf Girth – Max (cm)	0.059	0.060	0.009**	0.107	0.098	0.126	0.311	0.032*	0.491

* Indicates significance at $P \leq 0.05$ ** Indicates significance at $P \leq 0.01$

Appendix VII. **Lactate, heart rate and economy values from elite male soccer players during off-season and pre-season (mean ± S.D)**

	Subjects	Relative ($ml \cdot kg^{-1} \cdot min^{-1}$)	Absolute (l.min)	Max HR (cm)
Age (yrs)	n = 39	0.801	0.055	0.942
Body Mass (kg)	n = 39	0.116	0.000**	0.472
Stature (cm)	n = 39	0.102	0.034*	0.669
Sum of 8 Skin Folds (mm)	n = 39	0.204	0.466	0.195
Triceps Sf (mm)	n = 39	0.062	0.813	0.228
Subscapular Sf (mm)	n = 39	0.052	0.154	0.038*
Biceps Sf (mm)	n = 39	0.971	0.587	0.025*
Iliac Crest Sf (mm)	n = 39	0.554	0.317	0.509
Supraspinale Sf (mm)	n = 39	0.564	0.126	0.293
Abdominale Sf (mm)	n = 39	0.203	0.507	0.261
Front Thigh Sf (mm)	n = 39	0.487	0.989	0.437
Medial Calf Sf (mm)	n = 39	0.359	0.877	0.585
Thigh Girth - Mid (cm)	n = 39	0.279	0.005**	0.284
Forearm Girth – Max (cm)	n = 39	0.185	0.121	0.646
Calf Girth – Max (cm)	n = 39	0.821	0.000**	0.187
Heart Rate at LT1 (bpm)	n = 17	0.225	0.528	0.059
Heart Rate at LT2 (bpm)	n = 17	0.055	0.063	0.009**
Economy @ 11 (kph)	n = 19	0.383	0.669	0.187
Economy @ 14 (kph)	n = 19	0.158	0.580	0.418

Appendix VIII. Cardio-respiratory endurance and anthropometric associations from elite male soccer players; P-value correlations

	Subjects	Heart Rate @ LT1 (bpm)	Heart Rate @ LT2 (bpm)
Age (yrs)	n = 21	0.676	0.558
Body Mass (kg)	n = 21	0.165	0.524
Stature (cm)	n = 21	0.537	0.374
Sum of 8 Skin Folds (mm)	n = 21	0.879	0.705
Triceps Sf (mm)	n = 21	0.759	0.345
Subscapular Sf (mm)	n = 21	0.776	0.500
Biceps Sf (mm)	n = 21	0.409	0.293
Iliac Crest Sf (mm)	n = 21	0.754	0.849
Supraspinale Sf (mm)	n = 21	0.962	0.895
Abdominale Sf (mm)	n = 21	0.545	0.729
Front Thigh Sf (mm)	n = 21	0.788	0.664
Medial Calf Sf (mm)	n = 21	0.177	0.425
Thigh Girth - Mid (cm)	n = 21	0.068	0.946
Forearm Girth – Max (cm)	n = 21	0.116	0.868
Calf Girth – Max (cm)	n = 21	0.554	0.596
Economy @ 11 (kph)	n = 19	0.818	0.865
Economy @ 14 (kph)	n = 19	0.739	0.770

* Indicates significance at $P \leq 0.05$ ** Indicates significance at $P \leq 0.01$

Appendix IX. **Step-test heart rate values for elite male soccer players at lactate threshold stages 1 and 2; P-value correlations**

	2mmol/l speed (kph)	2mmol/l HR (bpm)	4mmol/l Speed (kph)	4mmol/l HR (bpm)	11kph Economy (kph)	14kph Economy (kph)
May (n = 14)	13.0 ± 2.0	156 ± 19	14.0 ± 2.0	169 ± 13	222 ± 14	215 ± 14
July (n = 16)	12.0 ± 1.0	158 ± 16	14.0 ± 2.0	178 ± 26	230 ± 28	213 ± 20
August (n = 5)	13.5 ± 0.5	162 ± 7	15.5 ± 0.5	170 ± 12	240 ± 34	123 ± 24

*Indicates significance at $P \leq 0.05$ ** Indicates significance at $P \leq 0.01$

Appendix X. **Elite female soccer player position specific anthropometric measures (mean ± S.D)**

	Subjects	Body Mass (kg)	Stature (cm)	Sum of 8 Skinfolds (mm)
Total Squad	n = 18	64.2 ± 9.0	166.5 ± 9.5	109.4 ± 35.4
Goalkeepers	n = 2	74.4 ± 1.6	173.8 ± 2.3	135.5 ± 14.5
Defenders	n = 5	61.0 ± 5.6	165.8 ± 2.3	117.8 ± 38.5
Midfield	n = 8	64.6 ± 9.7	165.0 ± 6.0	109.4 ± 35.4
Forwards	n = 3	60.4 ± 5.2	163.0 ± 6.0	104.3 ± 7.0

Appendix XI. Elite female soccer player anthropometric corrections (P-Values) (n=18)

	Sum of 8 Skin Folds (mm)	Triceps Sf (mm)	Subscapular Sf (mm)	Biceps Sf (mm)	Iliac Crest Sf (mm)	Supraspinale Sf (mm)	Abdominale Sf (mm)	Front Thigh Sf (mm)	Medial Calf Sf (mm)
Body Mass (kg)	0.022*	0.026*	0.620	0.438	0.112	0.013*	0.326	0.274	0.136
Stature (cm)	0.194	0.310	0.761	0.162	0.314	0.143	0.311	0.687	0.182*
Sum of 8 Skin Folds (mm)	-	0.045*	0.145	0.159	0.014*	0.030*	0.551	0.006**	0.009**
Triceps Sf (mm)	0.022*	-	0.124	0.337	0.000**	0.000**	0.070	0.070	0.068
Subscapular Sf (mm)	0.145	0.124	-	0.002**	0.011*	0.036*	0.015*	0.047*	0.098
Biceps Sf (mm)	0.159	0.337	0.002**	-	0.192	0.488	0.516	0.145	0.135
Iliac Crest Sf (mm)	0.014*	0.000**	0.011*	0.192	-	0.000**	0.002**	0.011*	0.071
Supraspinale Sf (mm)	0.030*	0.000**	0.036*	0.488	0.000**	-	0.003**	0.064	0.062
Abdominale Sf (mm)	0.551	0.070	0.015*	0.516	0.002**	0.003**	-	0.536	0.768
Front Thigh Sf (mm)	0.006**	0.070	0.047*	0.145	0.011*	0.064	0.536	-	0.001**
Medial Calf Sf (mm)	0.009**	0.068	0.098	0.135	0.071	0.062	0.768	0.001**	-

* Indicates significance at $P \leq 0.05$ ** Indicates significance at $P \leq 0.01$

Appendix XII. A table representing repeat 5m and 30m elite female soccer sprint performances

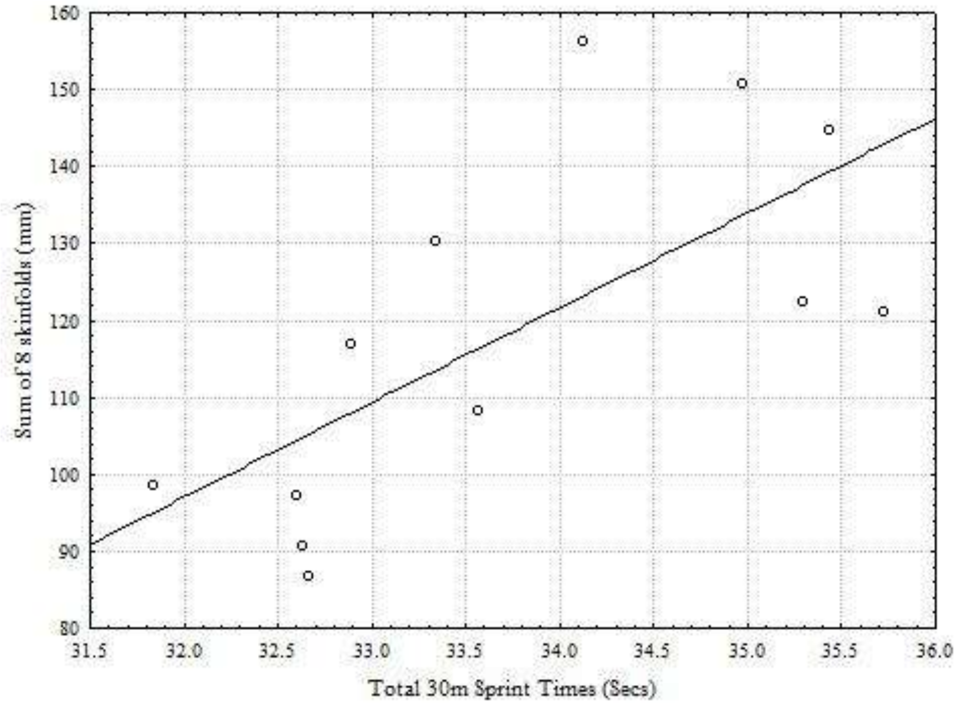
		7 x 5m Sprints			7 x 30m Sprints		
	Subjects	Fastest 5m (secs)	Mean 5m (secs)	Total Time (secs)	Fastest 30m (secs)	Mean 30m (secs)	Total Time (secs)
Total Squad	n = 13	1.02 ± 0.08	1.10 ± 0.07	7.66 ± 0.44	4.68 ± 0.32	4.83 ± 0.28	33.79 ± 1.95
Goalkeepers	n = 2	1.08 ± 0.01	1.11 ± 0.00	7.78 ± 0.05	4.71 ± 0.11	5.05 ± 0.05	35.35 ± 0.38
Defenders	n = 3	1.05 ± 0.03	1.10 ± 0.07	7.46 ± 0.23	4.57 ± 0.06	4.87 ± 0.21	33.38 ± 0.75
Midfield	n = 7	1.04 ± 0.07	1.10 ± 0.07	7.66 ± 0.44	4.72 ± 0.28	4.80 ± 0.25	33.64 ± 1.80
Forwards	n = 1	0.94 ± 0.00	1.12 ± 0.00	7.82 ± 0.00	4.36 ± 0.00	4.66 ± 0.00	32.60 ± 0.00

Appendix XIII. **A table representing elite female soccer player repeat 5m and 30m sprint performance p-values (n=12)**

	Fastest 5m (Secs)	Mean 5m (Secs)	Total 5m Sprint Times (Secs)	Fastest 30m (Secs)	Mean 30m (Secs)	Total 30m Sprint Times (Secs)
Fastest 5m (Secs)	-	0.053	0.044*	0.064	0.049*	0.046*
Mean 5m (Secs)	0.053	-	0.000**	0.353	0.151	0.147
Total 5m Sprint Times (Secs)	0.044*	0.000**	-	0.337	0.132	0.129
Fastest 30m (Secs)	0.064	0.353	0.337	-	0.000**	0.000**
Mean 30m (Secs)	0.049*	0.151	0.132	0.000**	-	0.000**
Total 30m Sprint Times (Secs)	0.046*	0.147	0.129	0.000**	0.000**	-
Average Match HR (bpm)	0.148	0.656	0.635	0.036*	0.023*	0.021*
Maximum Match HR (bpm)	0.520	0.829	0.868	0.358	0.453	0.441
Minimum Match HR (bpm)	0.069	0.476	0.430	0.001**	0.000**	0.000**
Body Mass (kg)	0.153	0.225	0.210	0.919	0.461	0.454
Stature (cm)	0.333	0.285	0.270	0.996	0.591	0.580
Sum of 8 Skin Folds (mm)	0.254	0.484	0.464	0.056	0.012*	0.013*
Triceps Sf (mm)	0.372	0.794	0.783	0.219	0.036*	0.037*
Subscapular Sf (mm)	0.761	0.347	0.358	0.484	0.841	0.843
Biceps Sf (mm)	0.808	0.296	0.297	0.140	0.138	0.142
Iliac Crest Sf (mm)	0.730	0.865	0.884	0.318	0.121	0.125
Supraspinale Sf (mm)	0.170	0.545	0.546	0.221	0.113	0.110
Abdominale Sf (mm)	0.942	0.868	0.809	0.222	0.724	0.705
Front Thigh Sf (mm)	0.491	0.635	0.594	0.232	0.076	0.082
Medial Calf Sf (mm)	0.273	0.451	0.414	0.267	0.105	0.107

* Indicates significance at $P \leq 0.05$ ** Indicates significance at $P \leq 0.01$

Appendix XIV. **A scatterplot demonstrating the sum of 8 skinfold measure (mm) and total 30m sprint time results for elite female soccer players (n=12)**



Appendix XV. Borg's Rating of Perceived Exertion (RPE) Scale

rating	description
6	NO EXERTION AT ALL
7	EXTREMELY LIGHT
8	
9	VERY LIGHT
10	
11	LIGHT
12	
13	SOMEWHAT HARD
14	
15	HARD (HEAVY)
16	
17	VERY HARD
18	
19	EXTREMELY HARD
20	MAXIMAL EXERTION

Appendix XVI. A table representing GPS match distance and heart rate values (mean + S.D)

		Match Distances		Match Zone Distances				Heart Rate Zones	
	Subjects	Total (m)	Total (m.min)	Zone 5 (m)	Zone 5 (m.min)	Zone 6 (m)	Zone 6 (m.min)	HR Zone 5 (mins)	HR Zone 6 (mins)
Total Squad	n = 12	8273 ± 1608	113.0 ± 11.5	761 ± 255	11.0 ± 2.75	662 ± 242	7.86 ± 3.00	21.07 ± 12.57	12.14 ± 12.14
Goalkeepers	n = 0	-	-	-	-	-	-	-	-
Defenders	n = 3	9104 ± 777	113.0 ± 4.0	784 ± 134	9.29 ± 1.00	599 ± 147	7.29 ± 2.43	22.12 ± 11.42	6.48 ± 5.06
Midfield	n = 7	7356 ± 691	113.0 ± 11.5	761 ± 255	11.1 ± 2.70	662 ± 242	8.04 ± 2.81	19.23 ± 10.13	12.14 ± 12.14
Forwards	n = 2	9341 ± 244	106 ± 3.0	867 ± 89	9.93 ± 1.57	707 ± 28	7.95 ± 0.66	14.15 ± 6.05	4.06 ± 4.06

Appendix XVII. A table representing individual elite male soccer player sum of 8 skinfold values EOS, PTP and EOP

	EOS (mm)	PTP (mm)	EOP (mm)
Mean ± S.D	59.3 ± 20.7	70.0 ± 28.8	66.1 ± 26.0
Subject 1	76.4	68.2	63.7
Subject 2	63.6	79.2	74.3
Subject 3	50.3	59.3	52.6
Subject 4	74.4	82.8	74.8
Subject 5	67.5	60.2	61.9
Subject 6	46.3	48.8	45.6
Subject 7	43.3	58.8	59.3
Subject 8	60.3	62.6	62.6
Subject 9	64.7	64.1	60.3
Subject 10	55.0	62.6	57.7
Subject 11	40.8	45.4	45.3
Subject 12	38.6	41.2	40.1
Subject 13	55.2	70.0	58.3
Subject 14	60.8	67.6	63.5
Subject 15	71.9	83.9	76.0
Subject 16	61.3	64.7	64.7
Subject 17	72.8	76.5	75.6
Subject 18	52.4	52.7	46.4
Subject 19	58.6	58.7	60.1
Subject 20	79.9	98.8	89.4
Subject 21	53.8	57.1	57.2
Subject 22	46.3	42.2	48.4
Subject 23	71.7	76.2	71.9
Subject 24	64.7	76.1	70.1
Subject 25	54.6	49.3	50.1
Subject 26	44.8	46.0	43.9
Subject 27	75.4	74.7	77.5
Subject 28	70.9	76.5	92.1

Appendix XVIII. A table representing individual elite male soccer player $\dot{V}O_{2max}$ values EOS, PTP and EOP

	EOS ($ml \cdot kg^{-1} \cdot min^{-1}$)	PTP ($ml \cdot kg^{-1} \cdot min^{-1}$)	EOP ($ml \cdot kg^{-1} \cdot min^{-1}$)
Mean ± S.D	55.5 ± 4.8	56.9 ± 6.5	59.9 ± 6.1
Subject 1	56.5	55.5	59.3
Subject 2	51.9	50.0	55.6
Subject 3	54.5	59.9	57.4
Subject 4	60.2	66.2	67.7
Subject 5	54.9	53.3	58.0
Subject 6	51.9	52.9	57.9
Subject 7	55.6	62.9	59.4
Subject 8	61.5	62.4	61.4
Subject 9	54.6	50.8	64.5
Subject 10	56.4	56.2	60.0
Subject 11	52.7	56.3	56.0

Appendix XIX. A table representing individual elite female soccer player performance values

		Sum of 8 Skinfolds (mm)	Mean 30m (secs)	Total High Intensity Efforts
	Mean ± S.D	109.4 ± 35.4	4.73 ± 0.37	289 ± 75.0
Goalkeepers	Subject 1	121.0	5.10	-
	Subject 2	150.8	5.00	-
Defenders	Subject 3	90.7	4.66	248
	Subject 4	144.8	4.52	277
	Subject 5	108.1	4.80	214
	Subject 6	156.3	4.88	-
Midfielders	Subject 7	98.6	4.55	364
	Subject 8	86.7	4.67	221
	Subject 9	144.8	5.06	-
	Subject 10	74.0	4.36	-
	Subject 11	130.3	4.76	265
	Subject 12	122.5	5.04	-
	Subject 13	116.8	4.70	244
Forwards	Subject 14	97.3	4.66	344